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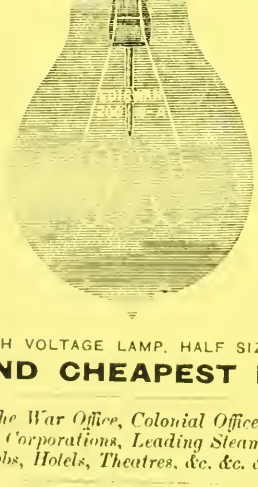

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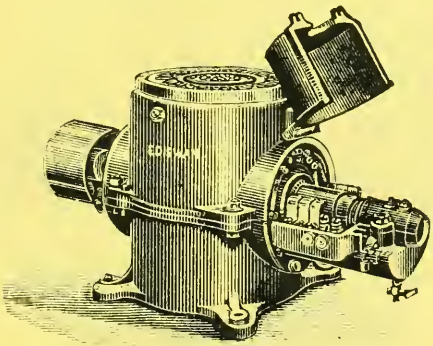

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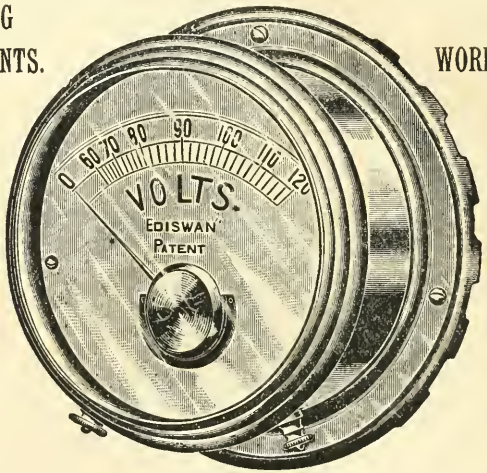

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New York:
SPON & CHAMBERLAIN, 12, CORTLANDT STREET.
1896.

PREFACE.

Self-help seems to be the guiding spirit of the present age, and amateur workmen are multiplying on all sides. With this development of popular taste comes a growing demand for handy practical books, containing the necessary hints and instructions, without enlarging on the theories and principles, or discussing the historical stages, of the particular art or industry under consideration.

The original volume of 'Workshop Receipts' was prompted by a desire to afford technical knowledge in a cheap and convenient form. Its success led to the publication of a Second Series, devoted to trades of a more or less Chemical character.

The present volume is a further instalment of valuable information connected with Electrical and Metallurgical matters. Within the last few years immense strides have been made in the application of Electricity, and it has become almost a domestic science. The theoretical treatment of this subject has received abundant attention; but the details of its practical employment have hitherto only appeared in fragments, in stray pamphlets and periodical literature. The article on Electrics, here presented, embraces a host of facts and instructions in an accessible form, and should prove eminently useful to the many who are adopting electric bell and lighting systems, or who take an interest in the construction and working of batteries, or the manipulation of microphones, phonographs, and similar novelties. The Metallurgical articles, in their practical features,

are far ahead of any existing work, being brought down to the most recent dates, and including some subjects on which the scantiest possible information has before been issued in a collective form.

In the editing of the present series, one or two improvements have suggested themselves, and these, coupled with the carefully-prepared contents and index, should ensure the book a reception equal to that which has been accorded its two predecessors.

CHARLES G. WARNFORD LOCK.

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Alloys: properties, characters, components, general principles for making, how to melt metals, fluxes for alloys, fusibility of metals, order of melting ingredients of alloys, table of fusing-points, furnaces for melting brass and other alloys, crucibles for melting alloys, casting mixed metals, right moment for pouring, moulding articles in relief, composition for core for difficult jobs. Aluminium bronze; Amalgams (copper, gold, iron, silver, sodium, tin, zinc); Bell-metal; Brass (composition and qualities, with table of proportions of ingredients and nature of metal produced; stamping, dipping, pickles, mottling, deadening, frosting, ornamenting; sheet brass; crucibles, furnaces, and order of melting the ingredients; formulæ for varieties of brass for special purposes; Dick's "delta metal"); Bronze (composition for various purposes, Thurston's experiments and formula for maximum strength, Tobin's alloy; details of manufacture of bronze figures); Fusible Alloys; German Silver; Gun-metal; Iron Alloys (characters conferred upon iron by alloying it with lead, copper, arsenic, tin, chromium, tungsten, silver gold, carbon, sulphur, phosphorus, silicon, nickel, antimony); Jewellers' Alloys (Algiers metal, Argentin, Ashberry metal, blue gold, Britannia metal, chrysocale, common jewelry, dipping metal, English metal, feuille morte, fine gold, gilding metal, jewelry gold, Mannheim gold, minòfor, mock gold, Queen's metal, red gold, ring gold, tubania, vert d'eau, white gold, electrum, yellow dipping, Sauvage's alloy, Parker's alloy); Manganese (bronzes and alloys with iron, copper, German silver, and tin; Delatot's white metal); Muntz's metal; Pewter; Phosphor Alloys (introduction of phosphorus into the molten metal; characters of the phosphorized alloys); Platinum Alloys; Solders (general characters; recipes for solders for aluminium bronze, brass, copper, hard solders, gold, silver, spelter, jewellers', middling hard, pewterers', sealing iron in stone, sealing tops of canned goods, soft solders, for steel, for tinned iron); Specular Alloys; Tungsten bronzes; Type-metal (general composition; formulæ for large type, music plates, printing type, small type, stereotypes); Miscellaneous Alloys (embracing compounds for friction bearings, steam-whistles, cylinders, taps, valve-boxes, pistons, mathematical instruments, rivets, coffins, pinchbeck, tombac, electrotypes, bullet metal, pin wire, jemmapes brass, similor, maillechort, flute-keys, arguzoid; composition of various Japanese and other bronzes, ancient coins, rings, figures, implements, pins; manu-

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ALLOYS.—Alloys are compounds of two or more metals. Every alloy may be regarded as a new metal, since it generally possesses properties different from those of the metals of which it is composed; but as the properties resulting from the combination of two metals rarely represent the mean of those metals, it is impossible to foretell the nature of a new alloy. All true alloys consist of compounds of metals in their definite chemical proportions; it is, however, a matter of some difficulty to obtain them in a separate state, owing to the readiness with which they dissolve in the excess of that metal which may happen to preponderate. There are some few alloys also in which the constituent metals seem to be merely mechanically mixed. Alloys possess the properties which are characteristic of metals, such as metallic lustre, conductivity of heat and electricity, and, in a greater or less degree, malleability, ductility, and tenacity. The specific gravity of an alloy appears to depend upon the amount of cohesion or attraction exerted by the constituent metals for one another, and to bear no reference whatever to the high or low specific gravity of those constituents in their free state. The specific heat of alloys was found by Regnault to be very nearly the mean of the specific heats of the constituents. The following rule for obtaining the specific heat of alloys gives a very close approximation to the figures obtained by actual experiment:—Multiply the specific heat of each constituent into the percentage amount of it contained in the alloy, and divide the sum of the products by 100. Alloys are not, as a rule, such good conductors of heat and electricity as the metals of which they are made. Their fusibility does not at all depend upon that of their constituents, but is generally greater; thus the melting-point of tin is 455° F. (235° C.), and that of lead 626° F. (330° C.), whereas a compound of 5 parts of tin and 1 part of lead melts at 381¼° F. (194° C.), and a compound of equal parts of both metals melts at 465¾° F. (241° C.). The ductility of alloys is usually slightly less than that of their most ductile constituent, and their hardness is greater than the mean hardness of both or all the metals. The tenacity of an alloy is often much greater than that of either of the metals alone.

Alloys of gold, silver, and copper, are generally superior in strength to any of the more fusible metals, and may be forged either when red-hot or cold. These 3 metals seem to unite in any proportions, and always form an alloy that is malleable when either hot or cold. Pure gold is but little used in the arts: it is too soft. It is generally alloyed with silver and copper, both to harden it and depreciate its value. Alloyed with copper, it forms gold of a red tint; with silver, it forms gold of a green tint; and alloyed with both copper and silver, it gives intermediate tints. Pure silver is but little used alone; it is generally alloyed with a small amount of copper, which does not change its colour, and greatly improves its malleability and working qualities. When gold, silver, or copper is alloyed

with the more fusible metals—lead, tin, and zinc—the alloy is less malleable and ductile than alloys of gold, silver, and copper. They are "extreme red-short," and when heated to redness they will fly to pieces under the hammer; and alloys of brass, bell-metal, &c., must be treated with caution, and should never be taken out of the mould while red-hot. Alloys of 2 parts copper and 1 zinc are very soft and malleable, and may be drawn by hammering or easily cut with a file, but an alloy of 1 copper and 2 zinc is as hard and brittle as glass, and may be easily pulverized. An alloy of 2 copper and 1 lead makes a soft, malleable metal, but is inferior to an alloy of copper and zinc. In alloys of 1 copper and 1 lead, the lead will ooze out in cooling. In alloys of 1 copper and 2 lead, the lead will not unite, but will sink to the bottom when cooling. Alloys of 6 copper and 1 tin make a very hard alloy, which gets harder and whiter the more tin is added. Alloys of tin and copper should not be too rapidly exposed to the air, for if a large percentage of tin is used it will strike to the surface and ooze out, or make hard spots in the casting. Alloys of zinc and lead cannot be made without the addition of arsenic, unless the lead is in very small quantity. Alloys of zinc and tin are very hard and brittle, and are but little used alone. By the addition of copper to alloys of these 2 metals, the alloy is rendered more malleable and soft. Arsenic makes all alloys hard and brittle, and is very dangerous to use. It is seldom used except to impart fluidity to the very infusible metals. Alloys of lead and tin are very malleable and ductile when cold, but at a temperature of about 200° F. (93½° C.), they lose the power of cohesion, and are exceedingly brittle. The alloys of tin and lead partake of the general nature of these 2 metals. They are soft and malleable when cold, even when a small amount of brittle antimony has been added. An alloy of 6 lead and 1 antimony is very soft and malleable, but an alloy of 3 lead and 1 antimony is very hard and brittle; and an alloy of 1 lead and 1 antimony is harder and more brittle than antimony. (E. Kirk.)

Melting.—Alloys are made by melting metals together. This operation may be carried on in an earthenware crucible, when small quantities are being operated upon; but when large masses of metal have to be dwelt with, as in the case of statues, &c., a reverberatory furnace must be employed to effect the melting. As a rule, the least fusible metal is placed in the crucible first, unless it be in very small quantity, and will dissolve readily in the other metal, in which case it goes in last; and if, as in the case of zinc, the volatilization of the metal be extremely rapid, it is introduced only the moment before the fused mass is ready to be poured into the mould or other receptacle. The order in which the metals are melted has a material effect upon the nature of the resulting alloy, for it has been proved by experiment that the latter often possesses different properties when the mixing has taken place in a different order. The fused metals should be kept thoroughly well stirred up until the mixture is complete; otherwise the heaviest metal will sink to the bottom of the mass, and the alloy will not be of uniform composition. This contingency is sometimes avoided by melting the mass a second time. When three metals have to be united together, they should first be melted in pairs, and afterwards together.

Guettier gives the following suggestions on the subject of fusing the metals:—(1) The melting-pot should be red-hot (a white heat is better), and those metals first placed in it which require the most heat to fuse them. (2) Put the metals in the melting-pot in strict order, following exactly the different fusing-points from the highest degree of temperature required down to the lowest, in regular sequence, and being especially careful to refrain from adding the next metal until those already in the pot are completely melted. (3) When the metals fused together in the crucible require very

different temperatures to melt them, a layer of charcoal should be placed upon them, or if there is much tin in the alloy, a layer of sand should be used. (4) The molten mass should be vigorously stirred with a stick, and even while pouring it into another vessel the stirring should not be relaxed. (5) Use a little old alloy in making new, if there is any on hand. (6) Make sure that the melting-pots are absolutely clean and free from traces of former operations.

Workmen who are unaccustomed to mixing or treating metals while in a liquid state will generally melt such metal upon a blacksmith's forge by applying heat so rapidly that the ladle will become red hot before the metal within it begins to melt. When it has melted, a dross rises to the surface, and is skimmed off by the workmen and thrown away. The skimming process is kept up as long as the ladle remains on the fire. Now, such a course is wrong, because, by applying heat too suddenly, the metals which fuse at lower degrees of heat, sweat out, and are burned before those which melt at higher temperatures become fluid. The dross, as it is commonly called, which rises to the surface, is in many cases the antimony, or hardening property of the alloy, and should not be thrown away. The surface of the melted metal should be kept covered with fine charcoal, which will prevent oxidation. A small lump of sal-ammoniac should also be kept upon the surface of the metal. The metal should always be stirred before pouring, otherwise the heaviest metals will separate and sink to the bottom of the ladle, and a constantly varying quality of metal will be the result. By melting the metal slowly, and keeping it properly fluxed as described, it will run sharp; each casting will be found uniform throughout, and the metal will be of equal hardness. In observing these simple precautions, much of the dissatisfaction now experienced in using antifriction alloys will disappear.

Nies and Winkelmann have examined the density of metals in a solid and in a liquid state, and find that, contrary to the generally accepted views on the subject, many melted metals expand when they solidify. The results of their experiments are embodied in a paper contributed to the Munich Academy of Sciences. Tin, slowly and carefully heated to its melting-point, floated on melted tin, and rose to its surface even after it had been submerged. By attaching pieces of copper to the floating tin, it was found that the increase of density by melting over solid tin was 0·7 per cent., a difference which is almost as great as that between tin at the freezing and the boiling points of water. Lead and cadmium did not yield as decisive a result. Zinc, however, behaved like tin, but showed only a contraction of 0·2 per cent. In the case of bismuth, the floating test is very easily carried out, as this metal shows as much as 3 per cent. Copper and iron showed a slight difference, the peculiarity in the case of iron being well known, and having been the subject of elaborate investigations by Wrightson.

Fluxes.—The best flux for alloys of copper and tin is rosin. It should be added when the metals are almost melted. Another good flux is sal-ammoniac. In using this flux the copper is usually melted first and the flux added. When it is in the mushy state, after the flux has been put in, the zinc and tin are added. A good flux for old brass is common rosin-soap. It should be added in small lumps, and stirred down into the metal when in the molten state. In forming alloys of different metals, the molten metals should always be kept under a covering of black glass or pulverized charcoal, to prevent oxidation.

Black flux, as it is commonly called, is composed of 7 parts crude tartar, 6 of saltpetre, 2 of common bottle-glass, and by some a small amount of calcined borax is added. These ingredients are first finely pounded and mixed, and then gradually heated in an iron pot or ladle so as to burn them together. Care should be taken not to overheat the

mixture, and as soon as it is thoroughly melted and mixed together it should be removed from the fire and allowed to cool. After it has cooled, it is finely pulverized and sifted, and is then ready for use. It has a great affinity for moisture, and should be protected against it by being placed in glass bottles, and the bottles corked up until wanted for use. This is the most powerful flux that can be made. It is but little employed in forming or fluxing alloys, but principally by assayers in assaying different kinds of metallic ores. In these assays the quantity of black flux used varies according to the quality of the ores, but the amount is generally about equal proportions of ore and flux. The ore is first roasted, and then finely broken up and mixed with the flux, and the whole is then rapidly heated in a crucible. If the flux does not make the slag sufficiently fluid to allow the metal to settle, a small amount of calcined borax is added, which makes the slag more liquid, and permits the metal to pass to the bottom of the crucible. The crucible is then removed from the fire, and the mixture is either poured from it or allowed to cool in it. After it has cooled, the slag is knocked off with a hammer, and a button of metal is obtained. When using this flux, the clay crucible, without either coal or graphite (plumbago), is preferred, for the flux is very hard on a crucible that contains either of these substances. Black flux is used by some foundry-men in melting the fine scrap-sweepings from the floor, and dross and refuse from the crucible. By melting these in a crucible with black flux, they obtain considerable amounts of metal from them that would otherwise be lost. In melting this refuse with black flux, the common clay crucible should always be used. (E. Kirk.)

Fusibility. — In forming alloys of metals, they do not combine with each other in their solid state (with the exception of mercury), owing to their chemical affinity being counteracted by the force of cohesion; and in order to form combinations of them, it is necessary to liquefy at least one of them, in which case they will unite, provided they have a chemical affinity for each other: thus bell-metal and brass are formed when pieces of tin or zinc are put into molten copper; and in the formation of alloys of this nature, where one of the metals is more fusible than the other, the less fusible metal should be fused first, and the more fusible metal added either in the molten or solid state. As the fusible metals are added, the temperature of the alloy should be reduced, to prevent oxidation or burning away of the fusible metals; for this reason, it is better to add the more fusible metals in the solid state, as by so doing the temperature of the metal is decreased. Alloys are always more fusible than the less fusible metals of which they are composed, and in some cases are more fusible than the most fusible metal they contain, as is the case in alloys of tin, lead, and bismuth. Some founders, in order to have the metal thoroughly united, first fuse the metals together, cast them into ingots, and remelt them for use. This practice is bad, for in the after-fusion there is always more or less of the more fusible metal burned away; and it is hard to determine the proportions of the alloy, or to have any certainty as to the quality of the castings. In melting ingots or scrap-alloys, they should be fused as rapidly as possible, and at the lowest available temperature, so as to avoid oxidation.

Some metals are almost infusible, and, when heated to the highest heat in a crucible, they refuse to melt and become fluid; but any metal can be melted by combination with the more fusible metals. Thus platinum, which is infusible with any ordinary heat, can be fused readily when combined with zinc, tin, or arsenic. This metal, by combination with arsenic, is rendered so fluid that it may be cast into any desired shape, and the arsenic may then be evaporated by a mild heat, and leave the platinum. Nickel, which barely fuses alone, will enter into combination

with copper, forming German silver—an alloy that is more fusible than nickel and less fusible than copper. This alloy is rendered the whiter, harder, and less fusible, the more nickel is added. The less fusible metals, when fused in contact with the more fusible metals, seem to dissolve in the fusible metals; rather than melt, the surface of the metal is gradually washed down, until the entire mass is dissolved or liquefied, and reduced to the state of alloy. In forming alloys of brass, in furnaces where heat enough cannot be obtained to fuse the copper separately, the alloy may be formed by heating the copper to the highest heat, and then adding the zinc or tin in the molten state, so as not to reduce the temperature of the copper.

In forming alloys with new metals, it is usual to melt the less fusible metals first, and then add the more fusible metals, and mix them by stirring well together; the rod used in stirring them should be heated to redness to prevent lowering the temperature or chilling the metal. In mixing alloys for bells, the alloy should be well stirred with an iron rod well heated, in which case part of the iron is dissolved, combines with the alloy, and gives the bell a better tone; but alloys of brass that are to be turned or finished should never be stirred with an iron rod, for the iron dissolved from the rod will cause hard specks in the alloy, if not thoroughly mixed. In forming fine alloys, the alloy should be stirred with a rod of the least fusible metal contained in the alloy, or with a wooden stick; the wooden stick, in many cases, is better than a metallic rod, for it causes the metal to boil slightly and unite more thoroughly, but it cannot be used in a little crucible with only a small amount of metal. When alloys are made that contain only a very slight quantity of a metal that is difficult to fuse, as in pewter, it is scarcely possible to throw into the melted tin the ½ per cent. of melted copper, with any certainty of the 2 metals being properly combined; and in forming this alloy, it is customary to melt the copper in a crucible, and then add to it 2 or 3 times its weight of melted tin; this dilutes the copper, and makes an alloy called temper or hardening. This alloy is very fusible, is melted in an iron ladle, and is added to molten tin or lead, to give it the desired hardness, and form pewter. (E. Kirk.)

Following are the fusing-points of the principal metals and other elements employed in alloys:—

Aluminium	1292° F.	(700° C.)
Antimony	797° F.	(425° C.)
Arsenic	773° F.	(412° C.)
Bismuth	504° F.	(270° C.)
Cadmium	608° F.	(320° C.)
Copper	1922° F.	(1050° C.)
Gold	2282° F.	(1250° C.)
Iron, cast	1922°-2192° F.	(1050°-1200° C.)
„ steel	2372°-2552° F.	(1300°-1400° C.)
„ wrought	2732°-2912° F.	(1500°-1600° C.)
Lead	622° F.	(330° C.)
Mercury	−40° F.	(−40° C.)
Nickel	2732°-2912° F.	(1500°-1600° C.)
Phosphorus	111° F.	(44° C.)
Platinum	4712° F.	(2600° C.)
Silver	1832° F.	(1000° C.)
Sulphur	239° F.	(115° C.)
Tellurium	716° F.	(380° C.)
Tin	455° F.	(235° C.)
Zinc	773° F.	(412° C.)

(Bayley.)

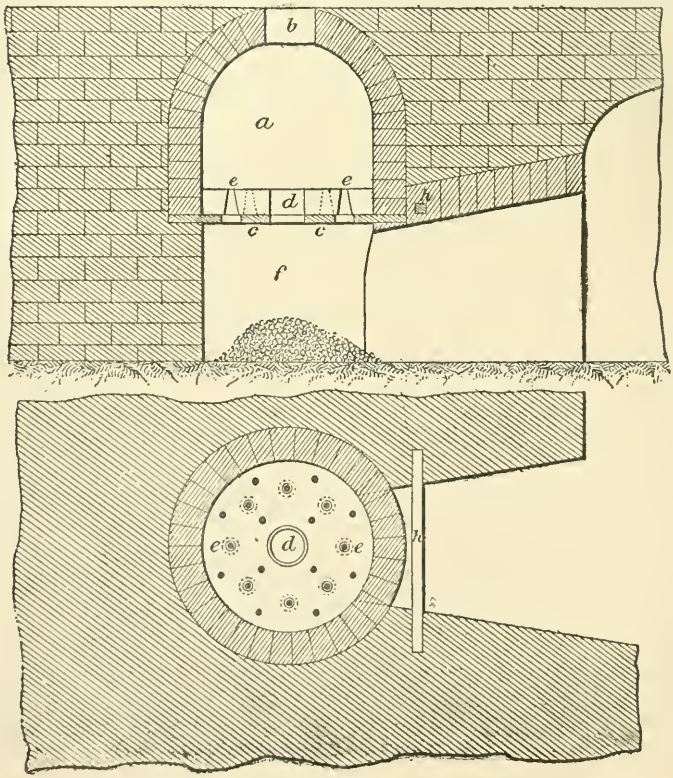
Furnaces. — Furnaces for melting alloys may be built of common brick and lined with fire-brick; but the best are made with a boiler-plate caisson, 20 to 30 in. diam. and 30 to 40 in. high, usually set down in a pit, with the top only 10 or 12 in. above the floor of the foundry. The ash-pit, or opening around the furnace, is covered by a loose wooden grating, that admits of the ashes being removed. The iron caisson is lined with fire-brick, the same as a cupola, the lining being usually 6 in. or more thick. The inside diameter of the furnace should not exceed the outside diameter of the crucible by more than 4 or 5 in., as greater space will require greater expenditure of fuel. These furnaces are liable to burn hollow around where the crucible rests; to avoid waste of fuel, they should be kept straightened up with fire-clay and sand. Sometimes these furnaces are built square inside, but they are inferior to the circular form and consume more fuel. Three or four such furnaces are commonly

arranged in sets giving a graduated scale of sizes, to suit the needs of larger or smaller castings. When the quantity of metal used is large, a blast is generally employed.

The common brass furnace usually depends on a natural draught, and connects by a flue with a chimney stack at the back. Three or four commonly share a single stack, each having a separate flue and damper. When the chimney does not give sufficient draught, the ash-pit may be tightly closed and a mild blast turned into the pit, to find its way up through the grates. The fuel may be hard coal or coke, broken into lumps about the size of hen's eggs; coke is preferable, as heating more rapidly, and thus lessening the oxidation of metal, but gas-coke from cannel coal is not admissible.

The ordinary cupola furnace is shown in Fig. 1. It consists of a circular chamber *a* built of fire-brick, rising in the form of a dome, in the top of which is a circular opening, carrying a cast-iron ring *b*, through which the pots and fuel are introduced. At the bottom is a bed-plate *c*, which is a circular plate of cast-iron having one large hole *d* in

FIG. 1.



the centre (for the withdrawal of ashes and clinkers), and twelve smaller ones *e* arranged symmetrically around it. Below the bed-plate is the ash-pit *f*, leading to an arched air-passage *g*, which supplies air to the ash-pit. Tapering cast-iron nozzles, 6 in. high, 3 in. diameter at the bottom, $1\frac{1}{4}$ in. at the top, and about $\frac{3}{4}$ in. thick, are placed over the twelve small holes *c*. The space between the top of the bed-plate and the top of the nozzles is built up with fire-brick and fire-clay until it forms a surface perfectly level with the top of the small nozzles, leaving the central hole free. These nozzles do the duty of a fire-grate, by admitting the air that supports combustion. The whole construction is enclosed in a solid mass of brickwork, and an iron bar *h* is built in over the air-way in front of the bed-plate, and resting on the walls forming the sides of the air-way, to give support. The dimensions of the furnace shown are 3 ft. 6 in. diameter, and 3 ft. 6 in. height from furnace-bed to crown of arch.

The ordinary melting furnace is shown in Fig 2. The fire-place *a* is

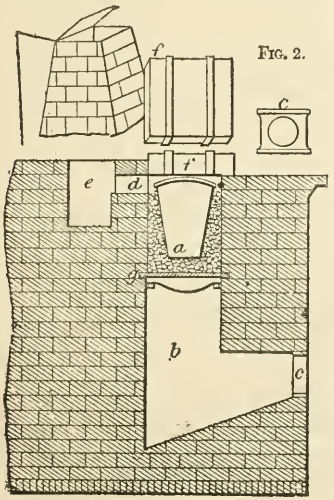


FIG. 2.

lined throughout with fire-brick, as well as the opening *d* into the flue and a portion of the flue *e* itself; *b* is the ash-pit; *c*, register-door of ash-pit, by which the draught is partially regulated; *f*, fire-brick cover for the furnace; *g*, fire-bars. It is built all round with common brick; and as many as six may use the same stack.

Fig. 3 illustrates the circular melting furnace, consisting of an iron plate *a*

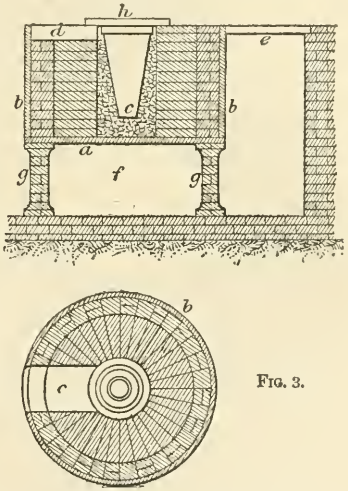


FIG. 3.

pierced in the centre by a circular hole of the size of the interior of the furnace, and crossed by the fire-bars; *b* is a sheet-iron drum riveted together, forming the shell of the furnace, and resting on the bed-plate; it is first lined on the inside with $4\frac{1}{2}$ in. of ordinary brick, and next with 9 in. of fire-brick; *c*, fire-place; *d*, flue leading to stack; *e*, iron grating for admitting air beneath the furnace; *f*, ash-pit; *g*, four small brick-work pillars, about 18 in. high, supporting the bed-plate; *h*, fire-brick cover to furnace. The draught is regulated by a damper in the flue or on the stack. The latter is an iron plate large enough to entirely cover the top of the

stack, hinged at one edge, and opened or closed by a lever.

A reverberatory furnace is illustrated in Fig. 4:—*a*, fire-place; *b*, ash-pit;

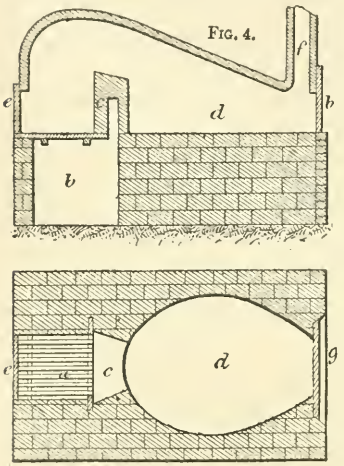


FIG. 4.

c, bridge; *d*, melting furnace; *e*, fire-door; *f*, flue leading to stack; *g*, door for feeding in and ladling out metal. The draught is regulated by the fire-door and the damper on the top of the stack.

Crucibles.—All the metals and alloys, with the exception of iron and the very fusible metals, are melted in crucibles, of which there are several different kinds. The principal ones in use are the Hessian pots, the English brown or clay pots, the Cornish and the Wedgwood crucibles—all extensively used for melting alloys of brass, bell-metal, gun-metal, &c.; but they are very brittle, and seldom stand more than one heat, yet are generally sold cheap, and some founders prefer to use a crucible only once, for crucibles often crack or burn through on the second heat. The best crucibles for all kind of alloys are made of graphite (miscalled plumbago and black lead). These are sold higher than any of the clay crucibles, but they are more refractory, and may be used for three or more successive heats without any danger of cracking or burning through. They are not so open and porous as the clay crucibles, and do not absorb so much of the metal, and for this reason they are to be preferred for melting valuable metals. When about to use a crucible, it should be heated gradually by putting it in the furnace when the fire is started, or by setting it on the top of the tyle or covering of the furnace, with the mouth down; it should be heated in this way until it is almost too hot to hold in the hands. Some founders stand a firebrick on end in the bottom of the furnace to set the crucible on. This prevents the crucible from settling with the fuel as it is burnt away. This way of supporting the crucible is a good idea when the furnace has a poor draught and the metal is melted slowly and it is necessary to replenish the fuel before the metal can be melted; but in furnaces where the metal is melted quickly, and it is not necessary to replenish the fuel in the middle of the heat, the crucible should be allowed to settle with the fuel, as the heat will then be more concentrated upon it. After the metal has been poured from the crucible into the mould or ingot, the crucible should always be returned to the furnace, and allowed to cool off with the furnace to prevent it from cracking. In forming alloys of brass, &c., a lid for the crucible is seldom used, but a covering of charcoal or some kind of flux is generally used on the metal. The metal to be melted in the crucible is generally packed in before the crucible is put into the furnace; and when it is desirable to put in more metal after the metal has been fused, it is put in with the tongs, if the metal is in large pieces; but when the metal to be added is in small pieces, it is put into the crucible through a long funnel-shaped pipe. The small end of this pipe is used for putting metals into the crucible, and the large end is used for covering the crucible to prevent the small pieces of fuel from falling into the crucible.

Casting.—When brass is ready to be poured, the zinc on the surface begins to waste with a lambent flame. When this condition is observed, the large cokes are first removed from the mouth of the pot, and a long pair of crucible tongs are thrust down beside the same to embrace it securely, after which a coupler is dropped upon the handles of the tongs; the pot is now lifted out with both hands and carried to the skimming place, where the loose dross is skimmed off with an iron rod, and the pot is rested upon the spill-trough, against or upon which the flasks are arranged.

The temperature at which the metal is poured must be proportioned to the magnitude of the work; thus large, straggling, and thin castings require the metal to be very hot, otherwise it will be chilled from coming in contact with the extended surface of sand before having entirely filled the mould; thick massive castings, if filled with such hot metal, would be sandburnt, as the long-continuance of the heat would destroy the face of the mould before the metal would be solidified. The line of policy seems therefore to be, to pour the metals at that period when they shall be sufficiently fluid to fill the moulds perfectly, and produce distinct and sharp impressions, but that the metal shall become externally congealed as soon as possible afterwards.

For slight moulds, the carbonaceous facings, whether meal-dust, charcoal, or soot, are good, as these substances are bad conductors of heat, and rather aid than otherwise by their ignition; it is also proper to air these moulds for thin works, or slightly warm them before a grate containing a coke fire. But in massive works these precautions are less required; and the facing of common brick-dust, which is incombustible and more binding, succeeds better.

The founder therefore fills the moulds having the slightest works first, and gradually proceeds to the heaviest; if needful, he will wait a little to cool the metal, or will effect the same purpose by stirring it with one of the ridges or waste runners, which thereby becomes partially melted. He judges of the temperature of the melted brass principally by the eye, as, when out of the furnace, and the very hot surface emits a brilliant bluish-white flame, and gives off clouds of white oxide of zinc, a considerable portion of which floats in the air like snow, the light decreases with the temperature, and but little zinc is then fumed away.

Gun-metal and pot-metal do not flare away in the manner of brass, the tin and lead being far less volatile than zinc; neither should they be poured so hot or fluid as yellow brass, or they will become sandburnt in a greater degree, or, rather, the tin and lead will strike to the surface. Gun-metal and the much-used alloys of copper, tin, and zinc, are sometimes mixed at the time of pouring; the alloy of lead and copper is never so treated, but always contains old metal, and copper is seldom cast alone, but a trifling portion of zinc is added to it, otherwise the work becomes nearly full of little air-bubbles throughout its surface.

When the founder is in doubt as to the quality of the metal, from its containing old metal of unknown character, or that he desires to be very exact, he will either pour a sample from the pot into an ingot-mould, or extract a little with a long rod terminating in a spoon heated to redness. The lump is cooled, and tried with the file, saw, hammer, or drill, to learn its quality. The engraved cylinders for calico-printing are required to be of pure copper, and their unsoundness, when cast in the usual way, was found to be so serious an evil that it gave rise to casting the metal under pressure.

Some persons judge of the heat proper for pouring by applying the skimmer to the surface of the metal, which, when very hot, has a motion like that of boiling water; this dies away and becomes more languid as the metal cools. Many works are spoiled from being poured too hot, and the management of the heat is much more difficult when the quantity of metal is small. In pouring the

metal, care should be taken to keep back the dross from the lip of the melting-pot. A crucible containing the general quantity of 40 lb. or 50 lb. of metal can be very conveniently managed by one individual, but for larger quantities, sometimes amounting to 1 cwt., an assistant aids in supporting the crucible by catching hold of the shoulder of the tongs with a grunter, an iron rod bent like a hook.

Whilst the mould is being filled, there is a rushing or hissing sound from the flow of metal and escape of air; the effect is less violent where there are two or more passages, as in heavy pieces, and then the jet can be kept entirely full, which is desirable. Immediately after the mould is filled, there are generally small but harmless explosions of the gases, which escape through the seams of the mould; they ignite from the runners, and burn quietly; but when the metal blows, from the after-escape of any confined air, it makes a gurgling, bubbling noise, like the boiling of water, but much louder, and it will sometimes throw the fluid metal out of the runner in 3 or 4 separate spurts; this effect, which mostly spoils the castings, is much the more likely to occur with cored works, and with such as are rammed in less judiciously hard, without being, like the moulds for fine castings, subsequently well dried. The moulds are generally opened before the castings are cold, and the founder's duty is ended when he has sawn off the ingates or ridges, and filed away the ragged edges where the metal has entered the seams of the mould; small works are additionally cleaned in a rumble, or revolving cask, where they soon scrub each other clean. Nearly all small brass works are poured vertically, and the runners must be proportioned to the size of the castings, that they may serve to fill the mould quickly, and supply at the top a mass of still fluid metal, to serve as a head or pressure for compressing that which is beneath, to increase the density and soundness of the casting. Most large works in brass, and the greater part of those in iron, are moulded and poured horizontally.

The casting of figures is the most complex and difficult branch of the founder's art. An example of this is found in the moulding of their ornaments in relief. The ornament, whatever it may be—a monumental bas-relief, for instance—is first modelled in relief, in clay or wax, upon a flat surface. A sand-flask is then placed upon the board over the model, and well rammed with sand, which thus takes the impress of the model on its lower surface. A second flask is now laid on the sunken impression, and also filled with sand, in order to take the relief impression from it. This is generally termed the cope or back mould. The thickness of the intended cast is then determined by placing an edging of clay around the lower flask, upon which edging the upper one rests, thus keeping the two surfaces at the precise distance from each other that it is intended the thickness of the casting shall be. In this process, the metal is economized to the greatest possible extent, as the interior surface, or back of the casting, is an exact representation of the relief of the subject, and the whole is thus made as thin in every part as the strength of the metal permits. Several modifications of the process just described are also made use of, to suit the particular circumstances of the case. What has been said, however, is a detail of the principle pursued in all matters of a similar nature. In conclusion, the following are instructions for a composition for cores that may be required for difficult jobs, where it would be extremely expensive to make a core-box for the same:—Make a pattern (of any material that will stand moulding from) like the core required. Take a mould from the same in the sand, in the ordinary way, place strengthening wires from point to point, centrally; gate and close your flask. Then make a composition of 2 parts brickdust and 1 of plaster of Paris; mix with water, and cast. Take it out when set, dry it, and place it in your mould,

warm, so that there may be no cold air in it. (*Iron.*)

Aluminium Bronze.—This alloy is composed of 90 parts of copper and 10 of aluminium. It is a definite chemical compound, and was discovered by Dr. Percy. It was manufactured for many years at Washington, near Newcastle, by J. Lowthian Bell, who obtained it by melting the copper in a crucible made of graphite or some other highly refractory material; the correct proportion of metallic aluminium was added to the melted copper, the two metals uniting with evolution of intense heat. Aluminium bronze is of a yellow colour, resembling gold; it is extremely hard and tenacious, and possesses great malleability and strength. It is admirably adapted for the working parts of machinery where great durability is required, and has a power of withstanding compression nearly equal to that of the best steel. Aluminium bronze containing 10 per cent. of aluminium possesses the maximum degree of hardness, strength, and tenacity; a larger proportion of aluminium renders the alloy weak and brittle. It has a specific gravity of 7·68; the weight of a cubic inch is 0·276 lb., and the tensile strength 32 tons per sq. in.

Amalgams.—Mercury unites with a large number of metals, forming definite chemical compounds called "amalgams." Some of these are solid, while others exist in a fluid state. It is probable, however, that fluid amalgams merely represent a solution in excess of mercury of some fixed compound of mercury with another metal, inasmuch as when a quantity of such fluid amalgam is pressed through the pores of a chamois-leather bag, a small portion of mercury passes through, leaving behind the solid amalgam, which, on examination, is generally found to have a fixed chemical constitution. The fluidity of an amalgam seems therefore to depend upon the presence of an excess of mercury over and above the amount theoretically required to enter into combination with the other metal.

The chemical affinity which causes mercury to combine with other metals is generally of a feeble character. Gentle pressure will drive out a considerable quantity of the combined mercury, leaving a combination in altogether different proportions from the original one. A moderate heat also is sufficient to decompose almost any amalgam. This fact was formerly made use of in the process known as *water-gilding*. The article to be gilded was covered with an amalgam of gold with excess of mercury, and then subjected to a strong heat. The mercury was driven off, leaving the article covered with a fine coating of metallic gold, which, on burnishing, regained its lustre.

The following are some of the most important amalgams:—

Copper Amalgam.—There are several methods of preparing this, the following being, perhaps, the best:—A mixture of finely-divided metallic copper (obtained by precipitating copper sulphate with metallic iron) and mercurous sulphate is triturated under hot water for ½ hour. After this, the water is repeatedly changed until it is no longer blue. The mass is then dried, kneaded well, and allowed to harden, when it consists of an amalgam of 7 parts mercury with 3 of copper. The peculiarity of this amalgam is its property of softening when kneaded, and becoming quite hard again after standing some hours. It has been used by Parisian dentists as a stopping for decayed teeth, though, owing to the poisonous nature of the copper, it is not to be recommended for this purpose.

Gold Amalgam.—This is formed when mercury is heated with powdered gold or gold-foil. It consists usually of 2 parts of gold to 1 of mercury. It has been found native near Mariposa, in California, and in the platinum region of Columbia.

The readiness with which mercury combines with gold is made use of in the extraction of the latter from its ores. The ore is crushed in an iron mortar, or battery, as it is termed. Water is introduced into each battery by a number of pipes. Mercury is placed in the batteries in small quantities, and unites with the

gold as the latter is liberated by the crushing process. The larger portion of the amalgam is afterwards found in the batteries, adhering to the plates, the remainder being caught by inclined plates placed outside the battery. The plates are cleaned by scraping off the adhering amalgam, first gently with a knife, and finally with a thick piece of hard gum or rubber, which scrapes the surface closely without cutting or scratching it. The plates are then washed with water, and prepared for use again by sprinkling mercury over them, and spreading the same evenly by means of a cloth, thus forming a freshly amalgamated surface.

Iron Amalgam.—Iron will not unite with mercury under ordinary conditions. Small quantities of an iron amalgam have, however, been formed by immersing sodium amalgam (containing 1 per cent. sodium) in a clear, saturated solution of ferrous sulphate.

Silver Amalgam.—This compound is formed by the union of mercury with finely-divided silver. Native silver amalgam has been found at Moschellandsberg, in the Palatinate, and in several other places. Mercury is used for silver extracting, in a process somewhat similar to that described above for the extraction of gold.

Sodium Amalgam.—Sodium and mercury combine readily under ordinary conditions by being brought into contact one with another. The union is attended with much hissing and spluttering, and with a considerable evolution of heat.

Tin Amalgam.—Tin and mercury combine readily at ordinary temperatures. If 3 parts mercury be brought into contact with 1 of tin, 6-sided crystals of tin amalgam are formed. Tin amalgam is used for silvering looking-glasses. When pulverized and rubbed on the polishing-stone, it forms a kind of mosaic silver. Electric amalgam may be made by melting tin and zinc together in various proportions in a porcelain crucible. The mixture is well stirred up, and when on the point of solidifying, the mercury is added and worked into the mass. The whole is next transferred to a mortar warm enough to keep the amalgam soft while it is well worked together, after which a piece of tallow or lard, not quite equal in bulk to the mass, is kneaded in until the amalgam attains the proper consistency.

Zinc Amalgam is formed by mixing and triturating zinc filings with mercury, at a heat somewhat below the boiling-point of the latter. It is usually prepared by pouring mercury into zinc at the temperature at which the latter is just kept in a fused state. Care must be taken to keep the liquid stirred, and to add the mercury slowly and in as fine a stream as possible.

Bell-metal.—An alloy of copper and tin in proportions varying from 3 to 5 parts of copper to 1 of tin. It is of a yellowish-grey colour, hard, brittle, and sonorous, and exhibits a fine-grained fracture. Cooled suddenly from a red heat, it becomes soft, but regains its hardness after being re-heated and cooled very slowly. Small house-bells are usually made of an alloy of 2 parts of copper with 1 of tin; but for larger bells a higher proportion of copper is needed.

The larger the proportion of copper in the alloy, the deeper and graver is the tone of the bells formed from it. The addition of tin, iron, or zinc causes them to give out a sharper tone. Where the quality of the tone is the chief object sought after, care must be taken to employ only commercially pure copper. The presence of lead, even in very small quantities, prejudicially affects the sonorousness of the alloy. Silver, on the contrary, is said to give sweetness to the tone. The presence of this metal has been detected in many old church bells, which, according to tradition, were cast from crucibles into which articles of silver had been thrown as votive offerings.

The composition of some varieties of bell-metal is shown below:—

(1) Copper, 39 parts; tin 11. This is the most sonorous of all the alloys of copper and zinc. (*Standard.*)

(2) Copper, 77 parts; tin, 21; antimony, 2. Paler and inferior to the above. (*Founders' Standard.*)

(3) Copper, 4 parts; tin, 1. Very deep-toned and sonorous.

(4) Copper, 3 parts; tin, 1. Used for church and other large bells.

(5) Copper, 17 parts; tin, 8. Best proportions for house-bells, hand-bells, &c.

(6) Copper, 72 parts; tin, 26½; iron. 1½. Used by the Paris houses for the bells of small clocks.

(7) Copper, 6 lb.; nickel, 1 lb.; melted and cooled; add 1 lb. zinc and ½ oz. aluminium; melt and cool; melt again, and add ½ oz. mercury and 6 lb. melted copper. Said not to tarnish nor crack, and to be lighter in weight and give better sound.

Brass.—Brass is perhaps the most useful and important alloy known. Its composition varies widely with the uses for which it is intended, but its constituents are copper and zinc, usually in the proportions of nearly two parts of the former to one part of the latter. Brass may also contain small quantities of tin and lead. The qualities which render this alloy so valuable may be briefly enumerated as follows:—It is harder than copper, and consequently better able to resist wear and tear. It is very malleable and ductile, and therefore admits of being either rolled into thin sheets, shaped with the hammer, drawn into fine wire, or raised by stamping into objects of various forms. It is readily fusible, and therefore easily cast at a lower temperature than copper. It resists the influences of the atmosphere better than copper, although, if unprotected by lacquer or varnish, it rapidly tarnishes and blackens on exposure to the air. Finally, brass has a fine yellow colour, and is capable of receiving a beautiful polish.

The malleability of brass varies with its composition and with its temperature; it is also affected, to a sensible degree, by the presence, even in minute quantities, of certain other metals. Some varieties of brass are malleable only when cold, others only when hot, and others, again, are never malleable. At a temperature just below its fusing-point, brass, like copper, is brittle, and may be powdered in a mortar. Alloys of copper and zinc present a great variety of colour, ranging between the reddish hue of the former and the bluish-white of the latter; the transition is gradual, and passes through all the intermediate stages of yellow. The table on page 14 represents the intensity of colour, hardness, and fusibility possessed by these different alloys.

During the process of stamping brass, it must be hardened or tempered from time to time. At the end of the process, it has lost its colour, owing to the formation of a coating of oxide during the tempering operations. This coating is easily removed by plunging the metal into nitric acid, and then washing it thoroughly with water. A brilliant metallic surface is thus produced, ready to receive the customary layer of lacquer or varnish. This cleansing process, is known as "dipping." If the brass contain any impurities, dipping will not impart to it a brilliant surface. The colour produced by dipping varies according to the strength of the acid; this is due, it is believed, to the fact that the metals constituting the alloy are acted upon to a greater or less degree by acids of different degrees of dilution.

The operation of dipping is performed in the following way:—The object, with a black coat of oxide, is plunged into nitric acid containing 1 part of the pure acid to 7 or 8 of water. It is allowed to "pickle," as it is termed, in the acid solution until the crust can be detached by rubbing the surface of the metal gently with the finger, when it is withdrawn, and washed immediately in water. It is next dipped into a much stronger acid solution, where it remains until the "curd" appears, or until the surface of the metal is entirely covered with minute bubbles of gas. This solution should be about twice as strong as the one previously used. The brass must then be washed with a plentiful supply of water, and roughly dried in cold sawdust. It is afterwards dipped, with the particles of wood still adhering to its surface, into strong nitric acid, where it remains only a few moments, then rinsed

Atomic Constitution.	Percentage Composition.	Colour of Fracture.	Inverse order of Hardness.	Inverse order of Fusibility.	Nature of the Brass.
Cu	100·00	Tile Red	20	15	Copper.
10Cu + Zn	90·72 + 9·28	Reddish-yellow 1	21	14	Similor, &c. (Several of these are malleable at high temperatures.)
9Cu + Zn	89·80 + 10·20	„ „ 2	20	13	
8Cu + Zn	88·60 + 11·40	„ „ 3	19	12	
7Cu + Zn	87·30 + 12·70	„ „ 4	18	11	
6Cu + Zn	85·40 + 14·60	Yellowish-red 3	17	10	
5Cu + Zn	83·02 + 16·98	„ „ 2	15	9	Bath-metal.
4Cu + Zn	79·65 + 20·35	„ „ 1	16	8	Dutch brass.
3Cu + Zn	74·58 + 25·42	Pale yellow	14	7	Rolled sheet brass.
5Cu + 2Zn	71·43 + 28·57	..	..	..	Ordinary brass.
2Cu + Zn	66·18 + 33·82	Full yellow 1	13	6	British brass.
19Cu + 12Zn	60·00 + 40·00	„ „	15	6	Muntz's metal.
Cu + Zn	49·47 + 50·53	„ „ 2	12	6	German brass.
Cu + 2Zn	32·85 + 67·15	Deep yellow	10	6	„ (watch-makers').
8Cu + 17Zn	31·52 + 68·48	Silver white 1	5	5	Very brittle (Too hard to file or turn.)
8Cu + 18Zn	30·30 + 69·70	„ „ 2	6	5	„
8Cu + 19Zn	29·17 + 70·83	Silver grey 1	7	5	„ (Lustre nearly equal to speculum metal.)
8Cu + 20Zn	28·12 + 71·88	Ash grey 3	3	5	Brittle
8Cu + 21Zn	27·10 + 72·90	Silver grey 2	9	5	„
8Cu + 22Zn	26·24 + 73·76	„ „ 1	8	5	Very brittle
8Cu + 23Zn	25·39 + 74·61	Ash grey 4	1	5	Barely malleable.
Cu + 3Zn	24·50 + 75·50	„ „ 1	2	4	Brittle.
Cu + 4Zn	19·65 + 80·36	„ „ 2	4	3	White button metal.
Cu + 5Zn	16·36 + 83·64	Very dark grey	11	2	Brittle.
Zn	100·00	Bluish-grey	23	1	Zinc.

with a little water, and immediately afterwards thoroughly washed with water containing argol in solution. It is finally dried in hot sawdust, after which the surface is ready for the lacquer or varnish.

Another dipping bath, which has been recommended, consists of hydrochloric acid and alum. It is said, however, that the lustre given is much duller and of a greenish hue, in comparison with that given by strong nitric acid. When dipping articles, have a bath of whiting and water close to the acid-bath. When the article has been dipped 4 seconds, remove it, and *instantly* plunge into the whiting and water, which removes at once all the acid and oxide, and it comes out a beautiful dead-gold colour, requiring to be only dried, warmed, and lacquered. Should the first dip be not sufficient, repeat the process, and end by a dip just in and out again quickly, having previously cleaned the article in water and dried it. Don't put it into the acid wet, because some parts being wetter than others, the acid will attack them unequally, and the result may be a cloudy mottled appearance on the surface. Never use a pair of iron tongs or forceps for holding the work when dipping; either suspend it from a brass wire, or make a pair of tongs out of a piece of $\frac{3}{4}$ by $\frac{3}{16}$ in. brass, something like a long pair of sugar-tongs. If obliged to use this process indoors, get a draught to carry away the brown fumes; if you have a fireplace not in use, make a board to fit it exactly, and at a convenient distance from the bottom cut a hole in it about 6 in. square; place the acid-bath close in front of this, and the air rushing through will carry the hurtful fumes up the chimney.

A mottled appearance is produced on brass by a "spotting" machine. A fair imitation can be made by the flat end of a piece of slate pencil. Put a piece of wood or metal, with a hole in it the size of the pencil, upon the piece of brass you wish to spot, and, having dipped the end of the pencil in water, place it in the hole, and turn it round a few times, when it will form a grey spot.

A dead appearance, called by the French *mât*, may be obtained by plunging the articles in a mixture of strong nitric acid 200 parts; sulphuric acid sp. gr. 1·845, 100; common salt, 1; sulphate of zinc, 2. The articles will require thorough rinsing. Another recipe, suitable for large work, consists of: 3 parts nitric acid, 1 sulphuric acid, 1 water, $\frac{1}{2}$ zinc sulphate. Dip the articles and rinse, again dip and rinse until the earthy yellowish dullness gives way to a clear *mât*, without earthiness.

For frosting small brass-work, fasten a circular scratch-brush, made of very fine brass wire, on the lathe, and having previously scoured the brass with strong pearlash lye, hold the work against the revolving brush, which must be driven at a good speed.

Holtzapffel introduced the following style of ornamenting flat surfaces:—The work (after being filed, scraped, and passed over with Water-of-Ayr stone) is clouded with a piece of charcoal and water, by means of which the entire surface is covered with large curly marks, which form the ground. The curls resemble an irregular cycloid pattern, with loops of $\frac{1}{4}$ in. to 1 in. in diameter, according to the magnitude of the work. Similar but smaller marks are then made with a piece of snake-stone, bluestone, or even a common slate pencil, filed to a blunt point. The general effect of the work much depends on the entire surface being uniformly covered; with which view the curls should be first continued round the margin; the central parts are then regularly filled in; after which the work is ready to be varnished.

Brass which is required for rolling into sheets should contain no antimony, as this metal renders the alloy very brittle, and extremely liable to crack. That which has to be turned contains invariably a small proportion of lead, usually about 2 per cent.; this addition is made when the crucible containing the fused metals is taken out of the furnace. The following is an analysis of a brass which is well adapted for this purpose:—Copper, 65·8; zinc, 31·8;

lead, 2·15; tin, 0·25. The presence of tin was believed to be accidental. Brass required for engraving upon should always contain a little tin, in order to render it sufficiently firm. Brass laminates well in the rolling mill cold, as long as it is kept sufficiently soft; but as by lamination the metal hardens and becomes brittle, it is necessary to restore its tenacity by annealing in an oven or reverberatory furnace. The same process of annealing is necessary in the manufacture of brass wire, which is obtained by drawing it through holes in steel plates, polished carefully and adjusted in series, graduated in size, so as not to diminish too rapidly, and thus render it necessary to employ so much power for drawing as would cause the breaking of the wire. Brass is not usually so prepared as to admit of its being hammered out, as is done in the manufacture of copper utensils; but a brass-foil or Dutch metal, of the colour and approaching the thinness of gold-leaf, is manufactured by beating out thin sheets of brass with hammers worked by water-power, making 300 or 400 strokes per minute.

Brass may be made either in a crucible, as in the ordinary Birmingham brass-foundries, or in a reverberatory furnace. The crucibles commonly used are circular, and made of fireclay; they are about 1 ft. deep, 8 in. diameter at the top, and 6 in. at the middle, internal measurements; they are also ¾ in. thick at the top, and 2 in. at the bottom; they contain about 84 lb.

The copper is first placed in the crucible, and the zinc is added to it bit by bit with much caution, as soon as the former metal is in a state of incipient fusion. The ingots of copper should be heated to redness before being put into the crucible. In Birmingham, the chief seat of the brass manufacture, the furnaces employed are square, their dimensions being 10 in. in the side and 24 in. in depth. Those used in London are circular in form. The flue between the furnace and the chimney should be narrow, and should lead out from the top of the furnace; its dimensions vary with those of the chimney, and with other conditions. Coke of the very best quality is the fuel employed. When the mixture is well fused together, the cinders are removed, and it is poured, if required for casting, into sand-moulds; if, on the contrary, it is to be used for rolling, it is cooled in close iron ingot-moulds, previously heated, oiled, and dusted lightly over in the interior with powdered charcoal. A loss of zinc invariably occurs by volatilization, which is always taken into consideration when weighing out the metal.

The following formulæ show the composition of different varieties of brass:—

For *button brass*, an alloy of 8 parts of copper and 5 of zinc is commonly used by the Birmingham makers, under the name of "platin." An alloy paler in colour, and used for the common buttons, consists of 25 of copper, 20 of zinc, 3 of lead, and 2 of tin.

For *fine brass*, an alloy of 2 parts of copper with 1 of zinc is the correct proportion; the metals are melted separately, poured suddenly together, and united by vigorous stirring. By raising the proportion of copper to 7 parts of copper and 3 of zinc, a bright-yellow and malleable alloy is obtained; 4 of copper and 1 of zinc yields a metal of darker colour than the last.

Brass for *fine castings* is an alloy of 62 parts of copper, 35 of zinc, 2 of lead, and 1 of tin; this is rather pale and brittle. An alloy used for the same purpose, and of a deep, rich colour, consists of 90 copper, 7 zinc, 2 tin, 1 lead.

For *gilding*, good proportions are: 64 parts copper, 32 zinc, 3 lead, 1 tin.

For *malleable brass*, good proportions are: 33 parts copper, 25 zinc, or, 3 copper and 2 zinc. These are malleable when hot.

For *soldering*, an alloy of 12 parts fine brass, 6 zinc, 1 tin, melted together, is most commonly employed.

For *turning*, the proportions are: 98 parts fine brass, 2 lead, both melted together; or, 65 copper, 33 zinc, 2 lead.

For *wire*, an alloy of 72 parts copper, 28 zinc, is commonly used; this alloy

must be afterwards hardened by tempering.

John C. Bull has succeeded in producing a new copper-zinc alloy which exhibits characteristics essentially superior to ordinary brass. The advantages claimed for the new alloy, which has been named "Bull's metal," are great strength and toughness, and a capacity for being rolled, forged, and drawn. It can be made as hard as mild steel, and when melted is very liquid, producing sound castings of close fine grain. The colour can be varied from that of yellow brass to rich gun-metal; the surface takes a fine polish, and, when exposed to the air, tarnishes less than brass. These latter characteristics will meet with ready appreciation for cabinet-work, harness fitting, &c. The metal when cast in sand has a breaking strain of 21 to 22 tons per sq. in.; when rolled or forged hot into rods, the breaking strain is 43 tons per sq. in.; and when drawn into wire of 22 B.W.G., of 67 tons per sq. in.

Bronze.—This alloy has been known and employed since very remote ages. It was used exclusively by the ancients for making swords and other sharp instruments, for coinage, statues, and many other useful and ornamental purposes. It is composed of copper and tin, sometimes with the addition of a little zinc and lead. Great variations are made in the proportions of the two chief constituents, according to the nature of the application for which it is destined. For statuary, the proportions used by the Brothers Keller, the most noted bronze-founders of modern times, were copper, 91·40; zinc, 5·53; tin, 1·70; and lead, 1·37. The bronze coinage of this country contains 95 parts copper, 4 of tin, and 1 of zinc. The addition of a little zinc to the alloy is an advantage, but too much diminishes its tenacity; lead is objectionable, owing to its tendency to sink after casting, thus destroying the homogeneity of the alloy. The metals should be melted rapidly to prevent loss of metal by oxidation, and the melted mass should be covered with a layer of charcoal, and kept constantly stirred. The operation is generally carried on in refractory crucibles, heated in a reverberatory furnace of suitable form. The cooling in the moulds must be as rapid as possible, in order to prevent the separation of the metals.

The composition of different kinds of bronze is shown below:—

For *edge-tools:* 100 parts copper, 14 tin; when properly tempered, this alloy is capable of taking nearly as fine an edge as steel.

For *gilding:* (1) copper, 82 parts; zinc, 18; tin, 3; lead, 1½; (2) copper, 83; zinc, 17; tin, 2; lead, 1; (3) copper, 70; zinc, 25; tin, 2; lead, 3. Nos. 2 and 3 represent extremes.

For *medals:* (1) copper, 89 parts; tin, 8; zinc, 3; this alloy takes a sharp impression by stamping; (2) (Chaudet) copper, 95 parts; tin, 4 or 5.

For *mortars:* copper, 93 parts; lead, 5; tin, 2.

For *statuary:* (1) copper, 88 parts; tin, 9; zinc, 2; lead, 1; (2) copper, 82½; zinc, 10½; tin, 5; lead, 2; nearly the proportions of the celebrated statue of Louis XV.; (3) copper, 90; tin, 9; lead, 1; (4) copper, 91; tin, 9: (5) copper, 91·4; zinc, 5·6; tin, 1·6; lead, 1·4; (6) copper, 89·35; tin, 10·05; zinc, 0·5; lead, 0·1.

In a paper lately read before the American Society of Civil Engineers, Prof. R. H. Thurston describes a new bronze alloy of maximum strength. The properties of this alloy were ascertained by Thurston in the course of his examination (in the mechanical laboratory of the Stevens Institute of Technology) of a series of 36 alloys of copper, tin, and zinc, in which the proportions of the copper were varied from 10 to 80 per cent.; of the tin, from 10 to 80 per cent.; and of the zinc, from 10 to 70 per cent. The results of these experiments pointed to an alloy of the proportions of 55 copper, 43 zinc, and 2 tin, as likely to be that possessing maximum strength, and on Thurston making the alloy, he found it to be of a good colour, close grained, and susceptible of high polish. It was also found to have immense strength, considerable hardness,

and moderate ductility, while it could also be forged if carefully heated. For purposes demanding toughness as well as strength, Thurston found, however, an alloy with less tin to be preferable, and he gives the proportions of 55 copper, 0·5 tin, and 44·5 zinc, as affording the best results. This alloy, he states, has a tensile strength of 68,900 lb. per sq. in. of original area, and 92,136 lb. per sq. in. of fractured area, while it elongated 47 to 51 per cent. (length of test sample not stated), and reduced to 0·69 to 0·71 of its original diameter before fracture. He also states that the shavings produced by the action of the turning tool on this alloy curled closely, and were tough and strong, like those of good iron. Thurston also refers to an alloy discovered several years ago by J. A. Tobin, but which appears not to be generally known. This alloy, which consists of 58·22 copper, 2·3 tin, and 39·48 zinc, had, when cast, a tensile strength of 66,500 lb. per sq. in. of original section, while when rolled hot its tenacity rose to 79,000 lb. per sq. in., and when moderately and carefully rolled cold, to 104,000 lb. per sq. in. It could also be bent double either hot or cold, and was found to make excellent bolts and nuts, while it could be forged at a low red heat.

Making Figures.—It is a singular fact that melted gold, silver, copper, and iron, if poured hot into a mould, will take an impression of all the details of the pattern from which the mould was made, only if the mould is made of sand. Zinc can be moulded in copper moulds, and that is the principal cause of the low price of spelter or zinc statuettes, known in the trade as imitation or French bronze. The real bronze is an alloy of copper, zinc, and tin, the two latter metals forming a very small part of the combination, the object of which is the production of a metal harder than the pure copper would be, and consequently more capable of standing the action of time, and also less brittle and soft than zinc alone would be. Let us follow a statuette through the different processes through which it has to pass from the time it leaves the hands of the artist who has modelled it to that when it reaches the shop where it is to be sold.

The original statuette is generally finished in plaster. The manufacturer's first operation is to have it cut in such pieces as will best suit the moulder, the mounter, and the chaser, for very few statuettes are cast all in one piece. Arms and legs are generally put on after the body is finished. The next operation is to reproduce the different parts of the figure in metal. For this the moulder takes it in hand to prepare the mould. He begins by selecting a rectangular iron frame, technically termed a flask, large enough for the figure to lie in easily. To this frame, which is 2 to 6 in. deep, another similar frame can be fastened by bolts and eyes arranged on the outside of it, so that several of these frames superposed form a sort of box. The workman places the plaster statuette, which is now his "pattern," on a bed of soft moulding-sand inside the first iron frame. The sand used for mould-making is of a peculiar nature, its principal quality being due to the presence of magnesia. Only in one locality in the world is found the best sand—that is at Fontenay-aux-Roses, a few miles from Paris, in France. This sand, when slightly damp, sticks together very easily, and is well fitted to take the impression of the pattern.

Once the pattern is imbedded in the sand, the workman takes a small lump of sand, which he presses against the sides of the figure, covering a certain portion of it. Next to this piece he presses another, using a small wooden mallet to ensure the perfect adhesion of the sand to the pattern. Each one of these pieces of sand is trimmed off, and a light layer of potato-flour is dusted both over the pattern and the different parts of the mould, to prevent them from adhering together. In course of time, the entire part of the pattern left above the first bed of sand, on which it has been placed, will be covered with these pieces of sand, which are beaten hard enough to keep together. Loose sand is now thrown over this

elementary brickwork of sand, if it may be so called, and a second iron frame bolted to the first one to hold the sand together, which, when beaten down, will form a case holding the elementary sand pieces of the mould in place. The workman now turns his mould over, removes the loose sand which formed the original bed of the pattern, and replaces it by beaten pieces, just as he had done on the upper side.

We can now easily conceive that if the mould is opened the plaster pattern can be removed, and that if all the pieces of sand are replaced as they were, we shall have a hollow space inside the mould, which will be exactly the space previously occupied by the pattern. If we pour melted metal into this space, it will fill it exactly, and consequently, when solidified by cooling, reproduce exactly the plaster pattern. For small pieces this will answer very well; but large pieces must be hollow. If they were cast solid, the metal in cooling would contract, and the surface would present cracks and holes difficult to fill. To make a casting hollow it is necessary to suspend inside the mould an inner mould or "core," leaving between it and the inner surface of the first mould a regular space, which is that which will be filled by the metal when it is poured in. This core is made of sand, and suspended in the mould by cross wires or iron rods, according to the importance of the piece. A method often used in preparing a mould, named by the French *cire perdue*, will help to illustrate this. The artist first takes a rough clay image of the figure he wants to produce. This will be the core of the mould; he covers it with a coating of modelling-wax of equal thickness, and on this wax he finishes the modelling of his figure. The moulder now makes his sand-mould over the wax, and, when it is completed by baking the mould in a suitable furnace, the wax runs out, leaving exactly the space to be filled up by the metal. The celebrated statue of Perseus, by Benvenuto Cellini, was cast in this way, and the method is very frequently employed by the Japanese and Chinese. Sometimes flowers, animals, or baskets are imbedded in the mould, and, after the baking, the ashes to which they have been reduced are either washed or blown out to make room for the metal. This can easily be done through the jets or passages left for the metal to enter the mould, and through the vent-holes provided for the escape of air and gases.

When the mould has cooled, it is broken to remove the casting it contains; and here is the reason why real bronze is so much more expensive than the spelter imitation. For each bronze a new sand-mould must be made, while the zinc or spelter can be poured in metallic moulds, which will last for ever. In this way the pieces are produced with but little more labour than that required to manufacture leaden bullets. These pieces, of course, do not receive the same expensive finish as the real bronze. When the casting is taken out of the mould, it goes to the mounter, who trims it off, files the base "true," prepares the sockets which are to receive the arms or other pieces to be mounted, and hands the piece to the chaser. The work of this artisan consists in removing from the surface of the metal such inequalities as the sand-mould may have left, and in finishing the surface of the metal as best suits the piece. The amount of work a skilful chaser can lay out on a piece is unlimited. In some cases the very texture of the skin is reproduced on the surface of the metal. This mode of chasing, called in French *ciselé*, and in English "skin-finish," is, of course, only found on work of the best class. Sometimes pieces are finished with slight cross-touches, similar to the cross-hatching of engraving. This style of finish, which is much esteemed by connoisseurs, is named "cross-riffled," or *ribouté*. After the chaser has finished his work, the piece returns to the mounter, who definitively secures the elements of the piece in their places.

The next process is that of bronzing. The colour known as "bronze" is that which a piece of that metal would take through the natural process of atmo-

spherical oxidation, if it were exposed to a dry atmosphere at an even temperature. But the manufacturer, not being able to wait for the slow action of nature, calls chemistry to his aid, and by different processes produces on the surface of the piece a metallic oxide of copper, which, according to taste or fashion, varies from black to red, which are the two extreme colours of copper oxide. The discovery of old bronzes, buried for centuries in damp earth, and covered with verdigris, suggested the colour known as vert antique, which is easily produced on new metal by the action of acetic or sulphuric acid. In the 15th century, the Florentine artisans produced a beautiful colour on their bronzes by smoking them over a fire of greasy rags and straw. This colour, which is very like that of mahogany, is still known as Florentine or smoked bronze. Bronze can also be plated with gold and silver, nickel and platinum, like every other metal. (F. Vors.)

On this subject, Gornaud says that the manufacturer of art bronzes begins by giving the style and general proportions to the artist, who is his first and most important assistant. The artist takes the clay, the model, the style, and arranges it into its varied forms; soon the architecture is designed, the figures become detached, the ornaments harmonize, and the idea embodied in the outline becomes clear. The manufacturer, before giving his model to the founder, should indicate with a pencil the parts which ought to be thickest, lest some be found too light, without, however, altering the form; he should also mark the parts to be cut in the mould to facilitate putting together. Care must be taken to rub with hard modelling wax all the projecting parts which serve to join the pieces, so that the turner may not want matter. He must carefully verify all the pieces separately, and cover with wax the angles and ends of the leaves—in a word, the weak parts. Generally the model is cast in half-red bronze, in the following proportions (the body of it is harder, and less easy to work):—

Copper	. .	91·60 per cent.
Zinc	. .	5·33 ,,
Tin	. .	1·70 ,,
Lead	. .	1·37 ,,

Objects destined to be gilded require a little more zinc than those of plain bronze. The models just described serve to make the moulds in moulding-sand, the moulds being afterwards baked in a stove heated to 572° F. (300° C.). They are fastened horizontally with binding screws, in order to run in the bronze; the temperature, when cast, varies from 2732° to 3272° F. (1500° to 1800° C.).

Fusible Alloys.—Several alloys having very low melting-points are used in the manufacture of children's toys, and for other purposes where great softness is required. They are chiefly as follows:—(1) 8 parts bismuth, 5 lead, 3 tin, melted together; melting-point, 202° F. (94·5° C.). (2) 2 parts bismuth, 5 lead, 3 tin; melts in boiling water. (3) 5 parts bismuth, 3 lead, 2 tin; melts at 197° F. (92° C.). (4) 15 parts bismuth, 8 lead, 4 tin, 3 cadmium; known as "Wood's patent"; has a brilliant metallic lustre, does not tarnish readily, and melts between 150° and 160° F. (65½° to 71° C.). (5) 5 volumes each of bismuth, lead, and tin, with 4 of cadmium, form an alloy which is quite liquid at 150° F. (65½° C.). (6) 4 volumes each of bismuth, lead, and tin, with 3 of cadmium, fuses at 153½° F. (67½° C.). (7) 2 volumes each of bismuth, lead, and tin, with 1 of cadmium, or 1 volume of each of the four metals, fuses at 155½° F. (68½° C.). (8) 1 part tin, 1 lead, 2 bismuth; melts at 200° F. (93·5° C.). (9) 15 parts bismuth, 8 lead, 4 tin, 2 cadmium; melts below 140° F. (60° C.). *N.B.*—All the alloys containing cadmium are liable to undergo rapid oxidation in contact with water.

German Silver.—This alloy is much used as a substitute for silver; it is composed of copper, zinc, and nickel. The proportions of the three metals are various. When intended as a substitute for silver, they are 50 parts copper, 25 zinc, and 25 nickel; castings,

such as candlesticks, &c., are made of an alloy containing 60 parts of copper, and 20 of each of the other two constituents. German silver is harder than silver, and susceptible of a high polish. It is of a greyish-white colour; fuses at a bright-red heat, the zinc being volatilized in the open air. The three metals, in a state of division and intimately mixed, may be melted together in a crucible, having copper at the top and bottom. The whole is covered with a coating of fine charcoal, and strongly heated in an air furnace with a strong draught. Or the copper and nickel may be first melted in the crucible, fragments of hot zinc being afterwards added. To aid the fusion of the nickel, the mixture should be well stirred. Lead is sometimes added, also iron, for the purpose of whitening the alloy.

Actual analyses of various kinds of German silver (including Argentan, Maillechort and Packfong) show the following proportions: —

(1) Copper, 50 parts; nickel, 20; zinc, 30; very malleable, and takes a high polish.

(2) Copper, 50 parts; nickel, 26; zinc, 24; good imitation of silver.

(3) Copper, 41 parts; nickel, 18; zinc, 41; rather brittle.

(4) Copper, 50 parts; nickel, 25; zinc, 25; good imitation of silver; white and malleable.

(5) Copper, 60 parts; nickel, 25; zinc, 20; for rolling and wire; very tough and malleable.

(6) Copper, 40½ parts; nickel, 31½; iron, 2½; zinc, 25½; made from Hillburghausen ore; equal to best Chinese sample.

(7) Equal parts of copper and nickel; recommended by Pélouze as being superior to any alloys containing zinc.

(8) Copper, 55 parts; nickel, 24; zinc, 16; tin, 3; iron, 2; white metal spoon, sold as German plate.

(9) 10 parts copper shavings and 4 parts arsenic in alternate layers, covered with salt, make a white alloy almost resembling silver.

Gun-Metal.—This is also an alloy of copper and tin, in the proportions of 8 or 9 parts of the former to 1 of the latter. It is a very tenacious metal, easily forged, and possesses a considerable amount of resistance; it is the metal of which large guns were formerly cast, whence the name. In order to make a perfectly uniform alloy, the melted metals should be cooled in the moulds as rapidly as possible. Gun-metal of the above composition has a specific gravity of 8·462; the weight of a cub. in. is 0·304 lb., and its tensile strength 15·2 tons to the sq. in.

The composition employed by the Kellers is—100 of copper, 9 of tin, and 6 of zinc. Fesquet states the proportions adopted by the chief European armouries as follows:—

	Copper.	Tin.
England	100	12·5
„	90	10
„	88–92	12–8
Austria, Bavaria, Prussia, Russia, Saxony	100	10
Spain	100	11

Iron Alloys.—All substances added to iron, according to Kirk, make it more fusible. Lead added in small quantity makes iron soft and tough, but in excess renders it "extreme cold-short." Copper induces "extreme red-short"-ness, and over 1 per cent. will make the iron "cold-short," but small quantities increase the strength of iron when cold. Arsenic imparts a silvery whiteness, but renders the iron brittle. Tin also whitens iron, and in about equal proportions makes it as hard as steel, but the alloy cannot be forged. The chromium alloy of iron is as hard as bort, but difficult to make. Tungsten steel, containing 6 to 8 per cent. of the former metal, is excessively hard and tough, but requires much care in manufacture. Silver renders iron hard, brittle, and very liable to corrosion. Gold produces toughness, and a yellow colour; this alloy is used for small iron castings. Carbon increases the fusibility; 1 to 2 per cent. makes hard cast iron, 5 to 6 foundry iron, less than 1 per cent. renders the iron very hard and brittle, and over 6 per cent. causes

extreme brittleness. Sulphur causes iron to be both hard and brittle, when either hot or cold, and it makes molten iron "short-lived;" fuel containing sulphur should not be used for melting iron in contact with the fuel. Phosphorus is very injurious to iron; ½ per cent. will cause iron to be very hard and brittle when cold, but it imparts a brilliant and white colour to iron more perfectly than any other metal. Silicon makes iron brittle and hard; it has a similar effect to phosphorus, but it is not so injurious. All cast iron contains more or less carbon, sulphur, phosphorus, and silicon, and, as these substances predominate, they form hard or soft, strong or brittle irons; and as all anthracite coal and coke contain more or less of these substances, anthracite or coke iron is less pure and more variable than charcoal iron, and, on account of the uncertain amount of these impurities contained in cast iron, it is very difficult to make an alloy of iron and other metals with any certainty as to the result: for this reason, alloyed iron is very little used.

Faraday and Stodart made a nickel-iron alloy by adding 3 per cent. of nickel to a good iron, and exposing in a crucible to a high temperature during several hours. The metals were melted; and on examining the button, the nickel was found combined with the iron. The alloy appeared to be as malleable and easily worked as pure iron; its colour was tolerably white when polished; the specific gravity was 7·804. On melting horse-shoe nails with 10 per cent. of nickel, the metals were found perfectly combined, but the alloy was less malleable, and easily broken under the hammer. Polished, it had a yellow tinge; its specific gravity was 7·849. This alloy was affected very slightly by humidity, compared to what would have happened had the iron been pure. According to Berthier, the alloy, consisting of—

Iron	0·917	12 at.
Nickel . . .	0·083	1 „

which is obtained by reducing a mixture of the 2 oxides in a crucible lined with charcoal, is semi-ductile, very tenacious, and has a granular fracture, slightly lamellar.

Iron in all states (malleable, cast, and sheet) unites with gold in any proportion by fusion:—3 parts iron and 1 of gold enter into fusion together at a temperature inferior to that necessary for melting iron; equal parts of the 2 metals give, by fusion, a greyish mass, somewhat brittle, and attracted by the magnet; with 6 parts gold and 1 of iron, a white alloy is obtained, which is attracted by the magnet, ductile while cold, and at a moderate heat becomes yellow, red, and blue; 9 of iron and 1 of gold form an alloy which resists the file, unless previously subjected to a red heat; with 28 of iron and 8 of gold, the alloy is as white as pure silver, and more yielding under the fire and hammer than ductile iron. According to Hatchett, the alloy formed with 11 parts gold and 1 of iron is very ductile, of great resisting power, and harder than gold. Without any preparation, it can readily be cut into blocks, laminated, or struck into medals. This alloy is of a pale yellowish-grey colour, approaching dirty white. Its specific gravity is 16·885.

Iron combines with tungsten by heating to the proper point, in a crucible, a mixture of 100 parts iron, 50 of the yellow oxide of tungsten, and a sufficient quantity of charcoal. After fusion and cooling, there is found a perfect button of a brownish-white colour, hard, rough to the touch, and of an even fracture. Hassenfratz obtained an alloy of the 2 metals, which forged easily enough, although slightly brittle; it was ductile, cracked in the tempering, and assumed in forging a partially fibrous partially granular texture. Karsten concludes from these experiments, that tungsten (in this respect resembling titanium) only increases the hardness of iron. The alloy, composed of—

Iron	0·63	6 at.
Tungsten . . .	0·37	1 „

is, according to Berthier, of a whiter grey than iron, shining, hard, more brittle than ordinary cast-iron, and of lamellar structure.

The union of iron and antimony is readily effected by fusion, and it would seem that it may take place in all proportions. These metals have a great affinity for each other. Their alloys are much more fusible than iron, and are white, hard, and very brittle. Their specific gravity is less than the mean of that of the 2 metals. According to Dr. Thompson, this alloy may be obtained by fusing in a crucible 2 parts antimony sulphide and 1 of iron. This alloy was formerly called *regulus martialis*, used in medicine for the preparation called "Mars' saffron," or "aperient antimony." The magnetic character of iron is much more diminished by its alloy with antimony than by almost any other metal. The iron is also rendered harder, much more fusible, and brittle, like cast-iron. Antimony, in uniting with iron, becomes harder and less fusible. Karsten added to cast-iron, after liquefaction, 1 per cent. of antimony; notwithstanding its volatility, this metal exercised on iron a worse influence than even tin. The iron became very brittle at all temperatures.

Karsten found that by the addition of 15 per cent. of fine silver to iron during the refinery operation, the quality of the iron was sensibly deteriorated: it did not forge well, became scaly, the bars presented cracks at the edges, and otherwise resembled hot-short iron. Analyses showed that it contained 0·034 per cent. of silver. It would appear, therefore, that silver has the same influence as sulphur upon iron, although in a less marked degree.

Iron and arsenic may be combined by fusion in any proportion. When the amount of arsenic is large, the magnetic character of the iron disappears. The alloy of these metals is more or less white, hard, brittle, and fusible, according to the amount of arsenic. It is crystallizable, its fracture more dense, and the texture closer than that of iron; according to Achard, similar to that of steel. Cadet asserts that this alloy will receive a brilliant polish, and that articles of jewellery are made from it.

Iron has a great affinity for chromium, and the 2 metals form alloys in all proportions. These compounds are generally hard, brittle, crystalline, of a greyer white than iron, of considerable lustre, less fusible, much less magnetic, and very much less soluble in acids than iron; the characters are the more prominent in proportion to the amount of chromium.

The alloy, composed of—

Iron . .	696·00	0·83	5 at.
Chromium	351·82	0·17	1 „

is nearly of a silver-white, with a fibrous texture, not easily yielding to the file, and very brittle. Merimée, with the aid of a cutler, tried 2 different alloys prepared by Berthier, the one containing 0·010 chromium, the other 0·015. Both forged extremely well; the former indeed appeared more easy to forge than pure cast-steel. Blades were made out of them for a sword and razor, and both were found to be of excellent quality, their edges being hard and lasting. But the most remarkable characteristic was the readiness with which this alloy received a beautiful damascening when rubbed with sulphuric acid. This damascening presented an agreeable variety of veins of a very brilliant silver-white, much resembling that which is obtained from steel alloyed with silver. The white parts, according to Berthier, are probably pure chromium, upon which the strongest acids have scarcely any action. In the Chrome Steel Works of Brooklyn, the chrome-iron ore is ground fine, and reduced with powdered charcoal in crucibles. The resulting mass is carefully weighed, ground, mixed with Swedish or wrought-iron, and melted in crucibles in charges of 75 lb. In 24 hours, the contents of 6 crucibles can be melted. The hardness of the resulting steel depends on the amount of chromium contained, which may vary from 0·25 to 2 per cent.

Copper, according to Karsten, may combine with any proportion of iron, augmenting its tenacity and hardness. Rinmann, for this reason, thinks that it would make, with raw cast-iron, an excellent alloy for anchors, mortars, an-

vils, cylinders, &c. 200 parts grey cast-iron, and 10 of red copper in thin shavings, immersed in linseed-oil, and submitted, with the addition of charcoal, to a very hot forge fire during 25 minutes, yield, according to Rinmann, a homogeneous metallic button, composed of 104 iron, 6 copper. This alloy is very hard; its density is 7·467. His experiments show that 200 parts copper and 10 of grey cast-iron, treated in the same way, yield a homogeneous button very ductile when cold. With 16 of copper and 1 of raw cast-iron, he obtained a ductile alloy that was magnetic, and resisted the file better than pure copper; the surface and fracture were of a fine red colour. Finally, 8 of copper and 1 to 4 of iron, give alloys which are harder than the preceding, but not perceptibly more brittle nor less coloured than copper. According to Lavoisier, iron containing copper possesses greater tenacity than any other, and becomes brittle only in the stages between a brown-red and deep-red heat: above or below this temperature it can readily be forged. Berthier affirms, in like manner, that iron containing copper possesses great tenacity when cold, but that it is brittle when hot, and can be forged only when above a reddish-white heat or below a cherry-red heat. It is probable, he says, that a large proportion of copper, 1 per cent. for example, would give the cast-iron additional tenacity, and make it better fitted to be employed in castings.

According to Dumas, tin enters into alloy with iron in all proportions. Heated to a high temperature, they melt; but at a moderate heat, separation takes place—a species of liquation. At first a quantity of pure tin, more or less considerable, is melted; then tin alloyed with iron; and there finally remains a less fusible alloy, consisting of tin and iron in other proportions, the iron predominating. Berthier states that a very small quantity of iron is sufficient to diminish the malleability of tin, blemish its white colour, and render it hard. The 2 metals enter into direct alloy when their oxides are heated with either charcoal or black flux. The alloy composed of—

Tin	0·351	1 at.
Iron	0·649	4 „

is of a clear iron-grey colour, crystalline, and sufficiently brittle to be reduced with ease to an impalpable powder. The alloy composed of—

Tin	0·50
Iron	0·50

is of a greyish-white colour, very brittle, with a granulated fracture. According to Bergmann, Karsten, and others, by melting iron with tin, 2 distinct and definite alloys are always obtained: the one composed of 21 tin and 1 iron; the other of 2 iron and 1 tin. The former is very malleable and harder than tin, without being so brilliant; the latter is not very malleable, and too hard to be pared with the knife.

Jewellers' Alloys.—The following are summarized from Fesquet:—

Algiers metal: (*a*) 90 tin, 10 antimony; (*b*) 94·5 tin, 5 copper, 0·5 antimony. *a* is used for spoons and forks, *b* for small hand-bells.

Argentin: 85·5 tin, 14·5 antimony; suitable for spoons and forks.

Ashberry metal: 78 to 82 tin, 16 to 20 antimony, 2 to 3 copper.

Blue gold: 750 gold, 250 iron; prepared by dipping iron wire into molten gold, then casting, hammering, and passing through a draw-plate.

Britannia metal: (*a*) 9 tin, 1 antimony; (*b*) 85 to 90 tin, 5 to 10 antimony, 0·5 to 2 zinc, 1 to 3 copper; (*c*) 85 tin, 5 antimony, 5 bismuth, 1·5 zinc, 3·5 copper.

Chrysocale: 9 copper, 8 zinc, 2 lead.

Common jewelry: 3 refined copper, 1 old Bristol bronze, and 25 tin for every 100 copper, the tin being replaced by a compound of lead and antimony when a fine polish is needed.

Dipping metal: 48 copper, 15 zinc.

English metal: 88 tin, 2 pure copper, 2 brass (containing 75 copper, 25 zinc), 2 nickel, 1 bismuth, 8 antimony, 2 tungsten.

Feuille morte (dead leaf): 700 gold, 300 silver.

Fine gold: 750 gold, 250 silver.

Gilding metal: 4 copper, 1 brass (containing 3 copper, 1 zinc), and 70 tin for each 80 copper.

Jewelry gold: 38·85 gold, 5·70 silver, 10·20 copper.

Mannheim gold: (*a*) 10 copper, 1·4 brass (containing 3 copper, 1 zinc), 0·1 tin; (*b*) 3 copper, 1 zinc, 0·5 tin.

Minofor: 3·25 copper, 67·50 tin, 17 antimony, 8·95 zinc.

Mock gold: (*a*) 16 copper, 7 platinum, 1 zinc; (*b*) 100 copper, 17 tin, 6 magnesia, 3·6 sal ammoniac, 1·8 quicklime, 9 bitartrate of potash; the copper is melted first, and the magnesia, ammonia, lime, and potash are successively added in small quantities; finally the tin is introduced in fragments, and the whole fused for 35 minutes.

Plate pewter: 90 tin, 7 antimony, 2 bismuth, 2 copper.

Queen's metal: (*a*) 3 to 9 tin, 1 antimony, 1 bismuth, 1 lead; (*b*) 2 copper, 50 tin, 4 antimony, 0·5 bismuth; (*c*) 24 brass (containing 7 copper, 3 zinc), 96 antimony, 30 tin; (*d*) 0·8 antimony, 18 bismuth, 32 lead.

Red gold: 750 gold, 250 copper.

Ring gold: 49·60 coin gold, 12·30 silver, 23·60 refined copper.

Tubania (Engestrum): 4 copper, 8 antimony, 1 bismuth, added to 100 tin.

Tubania (English): 12 brass (containing 7 copper, 3 zinc), 12 tin, 12 bismuth, 12 antimony.

Tubania (German): 0·4 copper, 3·2 tin, 42 antimony.

Tubania (Spanish): 24 iron and steel scraps, 48 antimony, 9 nitre; the iron and steel are heated to whiteness, and the antimony and nitre gradually added; 2 oz. of this is alloyed with 1 lb. tin; a little arsenic is an improvement.

Vert d'eau: (water green): 600 gold, 400 silver.

White gold (*electrum*): gold whitened by addition of silver.

Yellow (*antique*) *gold:* pure gold.

Yellow dipping: 2 bronze (containing 7 copper, 2 tin, 3 zinc), 1 copper, and 10 tin for each 640 copper.

The following forms a fusible malleable metal, easily worked by a silversmith, resisting oxidation, and capable of being soldered:—720 parts copper, 125 nickel, 10 bismuth, 90 zinc, 20 soft iron, 20 tin.

Sauvage has introduced the following alloy:—58 copper, 27 zinc, 12 nickel, 2 tin, 0·5 alumina, 0·5 bismuth; the ingredients are fused separately, mixed, and the whole is run down into a homogeneous mass, which is silvery, sonorous, malleable, ductile, tenacious, polishes well, and does not tarnish.

As a silvery-looking alloy, Parker recommends 70 copper, 30 manganese, 20 to 35 zinc, or, if not needing to be subjected to high temperature, 49 copper, 21 manganese, 5 to 10 iron, 5 to 10 zinc. The solder used for it contains 7 copper, 3 manganese, 1 to 2 silver.

Manganese Alloys.—Manganesian iron is mixed with copper, melted in a reverberatory furnace, and run into pigs. An alloy capable of being rolled is made by melting this together with zinc and copper. For a bronze capable of being forged, protoxide of manganese and protoxide of iron, together with sufficient coal-dust to reduce the two oxides, are added to copper. After melting, the product is similar to aluminium bronze. (*Jl. Soc. Chem. Ind.* i. 322).

Parson's manganese bronze is a member of that class of alloys in which copper forms the base and is alloyed with zinc and tin in various proportions, forming the different qualities of bronze, brass, yellow, and muntz metal, with addition of a proportion of *spiegeleisen*, ferro-manganese, or other forms of carburet of iron, combined with a sufficient quantity of manganese, by which addition these alloys are rendered more homogeneous, closer in texture, harder, and stronger.

The alloys composed as above are very numerous, and have been given a variety of names, according to the proportions in which the metals composing them are combined; but to explain the best means of putting Parson's process into practice, these alloys may be classified under 3 heads: (1) Those composed of copper and tin (gun-metal);

(2) copper, tin, and zinc (bronze); (3) copper and zinc (brass).

To obtain the best effects, the ferro-manganese to be used in the gun-metal alloys should be richer in manganese than that for the brass, while that for the bronze may be between the two, and regulated as conveniently as can be by the proportions of tin and zinc employed: that is to say, if little zinc is used in the bronze alloy, the ferro-manganese employed may be nearly as rich in manganese as in the gun-metal alloys; while if the zinc predominates, the ferro-manganese employed may be a trifle richer in manganese than that used in the brass alloys; and if the zinc and tin are about equal, the quantity of manganese contained in the ferro-manganese may be between that used for the gun-metal and that used for brass alloys. The ferro-manganese used to mix with the gun-metal alloys should contain 10 to 40 per cent. of metallic manganese, while that used to mix with the brass alloys should contain about 5 to 20 per cent.; and that used for the bronze alloys should be between the two, according to the proportions of tin and zinc employed.

In selecting the ferro-manganese to be used, it should contain as little silicon as possible: when *spiegel-eisen* can be obtained of the best quality, containing but a minute quantity of silicon, and 5 to 10 per cent. of manganese, it will be suitable to mix with the brass alloys, and it may even be used with the gun-metal alloys; but it will be found advantageous to apply for both, as well as the bronze, a ferro-manganese made as follows:—Procure ferro-manganese (as now manufactured for and used in steel-works) rich in metallic manganese, containing 50 to 60 or even 70 per cent.; melt this in a crucible under powdered charcoal, along with the requisite proportion of the purest wrought-iron scrap, to bring down the quantity of metallic manganese to any of the proportions before named. Supposing it is desired to employ a ferro-manganese, to mix with any of the before-named alloys, containing 20 per cent. of manganese, and a ferro-manganese, containing 60 per cent. of metallic manganese and say 1 per cent. of silicon, is melted with wrought-iron scrap in the proportion of 100 of ferro-manganese to 200 of wrought-iron scrap, a ferro-manganese containing the desired quantity of metallic manganese (20 per cent) will be obtained, containing only $\frac{1}{3}$ per cent. of silicon instead of 1 per cent., and so on for any other proportions required; not only this, but a still further portion of the silicon is eliminated, and the metal is refined by this second melting in a crucible as described. The quantity of ferro-manganese to be employed will vary both with the nature of the alloy and with the quality required in each particular alloy, and this will also to a certain extent have to be regulated by the quality of the copper, tin, and zinc employed. The purer these metals, the larger may be the quantity of ferro-manganese employed, and therefore no precise quantities can be specified; but generally, for ordinary gun-metal (composed of about 90 per cent. copper and 10 per cent. tin), $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. ferro-manganese may be added, containing say 20 per cent. metallic manganese; and as the tin is increased, the ferro-manganese should contain more manganese and less iron.

The quantity of ferro-manganese employed should be regulated according to the purposes for which the alloy is intended to be used; generally the effect produced is with the smaller quantities named to increase the strength of the alloy and the hardness slightly; and as the quantity of ferro-manganese is increased, the hardness is also increased, but at the same time the alloy becomes more brittle. A similar effect is produced by the addition of the ferro-manganese to the brass and bronze alloys. With the brass alloys, $\frac{1}{2}$ to 5 per cent. of the ferro-manganese may be employed with advantage for general purposes; and for the bronze alloys, any proportions between those for gun-metal and brass alloys may be advantageously used, these proportions being adjusted

according to the quantities of tin and zinc used: that is to say, the more tin used, the less should be the quantity of ferro-manganese.

In practice, the copper should be first melted in a crucible in the ordinary manner, and the *spiegel-eisen* or ferro-manganese, either with or without the addition of wrought-iron scrap, should at the same time be melted in a separate smaller furnace, capable of generating a high temperature, in a plumbago (graphite) crucible, under powdered charcoal; when it is completely fused, the copper also fused and at a boiling heat, the ferro-manganese should be poured into the copper, and the two well mixed together by stirring with an iron rod previously made red hot; the tin, zinc, or both should then be added in the usual way, and in the requisite proportions according to the kind of alloy it is required to produce. After the tin and zinc are added, the metal should be again well stirred with a red-hot rod, and skimmed; it may then either be poured into ingot moulds for future use, or it can at once be cast into moulds to produce any articles required.

In making castings, dry sand or loam moulds well coated with charcoal blacking are preferable to green sand moulds; the metal should be well skimmed before pouring, and it should be cast at as low a heat as possible, so long as it is attached to the thickest part of the casting, which, if possible, it should exceed in bulk, so as to solidify the last, and act as a feeder while the cast is cooling. If metallic moulds are employed, the alloy is rendered closer in texture and somewhat harder.

Parson's manganese bronze was recently subjected to a series of tests at Woolwich Arsenal, with the following results:—On fracturing an ingot of the alloy, the broken surfaces present a fine and close grain, resembling more nearly the fracture of the best qualities of steel than the coarsely granular appearance of the broken surface of ordinary bronzes. The alloy may be cast or forged, the latter operation being conducted at a red heat, and having the effect of considerably increasing its strength and toughness. When cast, the alloy is quite equal in ultimate strength to fair quality wrought-iron, and much superior to best gun-metal. Under the hammer, however, it acquires such qualities that it is virtually a new and valuable metal. Of the 6 specimens tested, 3 were cast and 3 forged—each series representing 3 different degrees of hardness. The first cast specimen, representing the tough quality, exhibited an ultimate strength of 24 tons per sq. in., an elastic limit of 14 tons, an elongation of $8\frac{3}{4}$ per cent. A second specimen of harder quality broke under a load of 22 tons, had an elastic limit of 14 tons, and the elongation amounted to $5\frac{1}{2}$ per cent. The third, of harder quality still, broke at $23\frac{1}{2}$ tons, had an elastic limit of nearly 17 tons, while the elongation was reduced to less than 4 per cent. The extraordinary changes produced by the operation of forging will be apparent from an inspection of the following figures, the specimens tested being forged samples of the same quality as the 3 specimens cast above mentioned. The first, or tough quality, when forged, had an ultimate strength of 29 tons, an elastic limit of 12 tons, and the elongation amounted to nearly 32 per cent. The forged specimen of the harder quality had an ultimate strength of nearly 29 tons, the elastic limit being over 13 tons, and the elongation more than $35\frac{1}{4}$ per cent. With the hardest quality, forging brought the ultimate strength to more than $30\frac{1}{4}$ tons, the elastic limit being 12 tons, with an elongation of $20\frac{3}{4}$ per cent.

Some years ago Berthier made several alloys of manganese protoxide and metallic copper in the proportions of 1 to 8, 1 to 4, 1 to 2, and with the manganese slightly in excess of the copper. These alloys were all ductile, the first being perfectly so, while the last, still very ductile, was also very tenacious and capable of taking a fine polish.

Experiments have been made in Paris

with a new alloy having a white colour, yet containing no nickel. It is said to be very strong and malleable. It is made of copper and ferro-manganese, the proportions being varied according to the purpose to which the alloy is to be employed. An alloy of 40 parts copper and 60 of ferro-manganese, with a suitable quantity of some appropriate flux, produces a metal of such tenacity that it surpasses the best steel armour-plates. The melted mixture is cast in blocks, and is perfectly malleable. To obtain a white metal that can be rolled out in sheets, the above alloy is melted again, and 20 or 25 per cent. of zinc or white metal added, which imparts to it the desired quality. A plate of the first-named alloy, 2 in. thick, was found by experiment to offer more resistance to a cannon-ball than a steel armour-plate of the same thickness. This new kind of "white bronze" is not to be confounded with the alloy used in America under the same name for gravestones and monuments, and which consists principally of zinc. (*Polyt. Notiz.*)

While most experimenters have succeeded in combining manganese and copper *in statu nascendi*—that is, by simultaneous reduction from their respective oxides—Heusler Brothers, of Dillenburg, recognised a greater advantage in reducing metallic manganese from pure pyrolusite for itself, and afterward alloying it in any required proportion with other metals. The reduction takes place in large plumbago (graphite) crucibles, with an admixture of carbon and of very basic materials, by which, after 6 hours' smelting in a powerful coke fire, "crude manganese" is obtained, this containing 90 to 92 per cent. manganese, 6 to 6·5 carbon, 0·5 to 1·5 iron, and 0·5 to 1·2 silicon. The crude metal can be refined to contain 94 to 95 per cent. manganese when it is remelted with a suitable flux, and this metal contains only combined carbon, while in its crude state graphitic carbon also is almost always present. The refined metal is white, with crystalline fracture, and it oxidizes slowly when exposed to damp air; it is, therefore, soon combined with copper, thus forming "manganese copper," with 70 parts copper and 30 manganese. The alloy is cast either in ingots or shot, and becomes a commercial article in this state; its fracture is of steel-grey colour and very close, and it is not difficult to combine it in any proportion with other metals or alloys, such as brass, bronze, gun-metal, bell-metal, yellow-metal, and others. The same combination has been found a very powerful "physic" in refining copper, because the manganese will take up all oxygen which is absorbed by the bath of refined copper in the refining furnace before it is made tough, either by an addition of lead or by an insertion of a pole of green wood.

"Manganese German silver" was made from 70 copper, 15 manganese, and 15 zinc; but as this alloy proved rather brittle in the rollers, the proportions were altered to 80 copper, 15 manganese, and 5 zinc, when a beautiful white and ductile metal was obtained, which would take a high polish.

Of far greater importance are the "manganese tin and zinc bronzes," which were perhaps among the first upon which experiments were made on a large scale. They were obtained by adding to an alloy of copper, tin, and zinc, a certain quantity of "manganese copper," viz., the combination of 70 copper with 30 manganese as above described, by which an increase of at least 9 per cent of strength is obtained over the ordinary alloy. This seems to be greatly due, as in the case of the refined tough copper, to a chemical action of the manganese; for all ordinary bronzes contain more or less of copper and tin oxides, which are reduced to metal by the action of the manganese. An addition of manganese seems, however, to have also physically a strengthening effect, and an addition of 3 to 6 per cent. of manganese copper has been experimentally found to suit the purpose best.

Manganese and tin combine as readily

as manganese and copper; tin, however, shows, as in ordinary bronzes, a tendency to separate itself in the middle of thick castings from the other alloys, because it remains longest in a fluid condition, and under the process of solidification it seems to get squeezed out of those parts of a casting which retain the heat longest.

An important series of experiments made at Isabelle-Hütte have shown that the strongest "manganese tin bronze" is obtained by alloying 85 copper with 6 tin, 5 zinc, and 5 manganese copper, so that the cooled product retains something above 1 per cent. manganese. The best mode of procedure is first to melt the copper in a crucible, then to add successively tin and zinc, but manganese copper only at the last moment, when the metals are well stirred up with a rod made from gas retort graphite; a reaction upon the oxides of the metallic bath is clearly noticed, as it begins to boil and to emit sparks after the addition of manganese, of which a portion is carried into the slag. Subjoined is a table of trials made with a series of rough ingots of the metal:—

No.	Cast in.	Copper.	Tin.	Zinc.	Manganese Copper.	Breaking strength, tons per sq. in.	Limit of elasticity, tons per sq. in.	Elongation. Per cent
1	sand	85	6	5	..	10·3	7·24	..
2	,,	85	6	5	4	10·34	8·4	2
3	iron	87	8·7	4·3	4	12·51	..	..
4	,,	85	6·9	5	6	12·13	..	6
5	,,	85	6	5	6	12·7	..	7
6	,,	85	6	5	10	11·05	..	5
7	sand	87	5·20	4·33	3·47	12·63	..	8·7
8	,,	87	5·20	4·33	3·47	12·7	..	8·9
9	,,	85	6	5	3	14·09	10·8	
10	,,	74	10	5 (7·66 lead)	3·3	12·06	8·9	.. ..
11	,,	78·7	8	(8 lead)	3·3	13·33	8·9	..
12	,,	82	9·8	4·9	3·3	12·7	9·5	..
13	,,	86·2	10·5	..	3·3	15·87	9·2	..

The absolute strength of these alloys is considerably enhanced when the ingots are subjected to judicious forging or rolling. The White Brass Co. of London, indeed, reaches in this manner with manganese bronze the strength of good steel plates, giving a breaking strain of 27 to 30 tons per sq. in.

Delatot's white metal is composed of 80 parts red copper, 2 manganese oxide, 18 zinc, 1 lime phosphate, fused together. To the melted copper is added the manganese in very small instalments; when this is dissolved, the lime phosphate is similarly introduced, and after the reduction has lasted ½ hour, the scum is removed from the surface of the bath, and the zinc is added about 10 minutes before running out. This alloy is said to equal gun-metal in tenacity and resistance, excel it in obviating friction, and cost much less. The fusion of the manganese oxide may be hastened by using a flux composed of 2 parts charcoal, 1 calcium fluoride, 1 sodium borate.

Muntz's Metal.—An alloy of copper and zinc. For rolling into sheets, the best proportions are 60 parts copper to 40 zinc; but for other purposes its composition is variable. It was patented in 1832 by Muntz of Birmingham, and has since superseded copper for sheathing the bottoms of ships. The alloy is made in a reverberatory furnace, the copper being melted first and the zinc

added afterwards. The fused mixture is run into clay-lined vessels and ladled from these, while still hot, into iron ingot-moulds. It is rolled into sheets or worked into bolts at a red heat; the sheets are subsequently "pickled" in weak sulphuric acid, and then washed with water. Fesquet states the composition for sheathing plates as 56 copper, 40·75 zinc, 4·5 lead.

Pewter.—Pewter is an alloy of lead and tin, containing sometimes copper, zinc, or antimony. There are three distinct kinds of English-made pewter, viz. (1) *Plate pewter*, used for dishes and plates, an alloy usually made without lead, and containing principally 90 parts tin, 7 antimony, 2 bismuth, and 2 copper; (2) *Trifle pewter*, employed for casting drinking vessels, &c., an alloy of 82 parts tin with 18 lead, and containing variable quantities of antimony; and (3) *Ley pewter*, containing 4 parts tin and 1 lead, employed for the larger wine measures. Owing to the poisonous nature of lead, which is apt to be dissolved by the acetic acid always present in beer, the French Government has prohibited the use of an alloy containing more than 18 per cent. of lead; if the lead be not in excess of this quantity, the tin seems to have the effect of neutralizing its poisonous properties. When made in the above proportions, pewter has a specific gravity of 7·8, so that any specimens of a higher specific gravity than this may be known to contain too high a percentage of the heavier metal. Pewter is a soft metal resembling tin, but duller and darker in colour. Plates and dishes are hammered out of the variety called plate pewter, but drinking vessels, &c., are always cast into moulds from the common variety.

Phosphor Alloys.—For the preparation of phosphorus compounds of metals, for example, phosphor-copper, Dr. Schwarz gives the following directions:—A mixture of bone-ash, silica, and carbon is placed in a crucible, and upon it a layer of granulated copper, which is in turn covered with the above mixture. The lid of the crucible is luted on. To make it melt more easily, some carbonate of soda and glass may be added, or a mixture of pulverized milk-glass with charcoal and powdered coke is used for lining and covering it. Take, for example, 14 parts of silica, 18 of bone-ash, and 4 of powdered carbon. This is mixed with 4 parts of soda and 4 of powdered glass, stirred up with a little gum water, and used to line the crucible. When this is dry, the copper is put in and covered with the same mass, and the whole is melted at a bright-red heat. The copper obtained flows well, and has a reddish-grey colour. It contains 0·50 to 0·51 per cent. of phosphorus.

The simplest method for introducing phosphorus into bronze is to stick a bar of the phosphorus into a tube of pinchbeck, one end of which is hammered together and closed tightly. After the phosphorus is put in, the other end is closed too. When the metal, which contains 32 parts of copper to 5 of zinc and 1 of tin, is melted, the tube charged with phosphorus is pushed down in it to the bottom of the crucible by means of bent tongs. The stick of phosphorus must always be kept under water until it is about to go into the pinchbeck tube, when it must be carefully dried, as the presence of any moisture would be sure to cause the metal to spurt or fly about.

Another way of introducing the phosphorus is as follows:—Get about 2 ft. of iron barrel from a gasfitter, the bore a little larger than the sticks of phosphorus; make an iron plug to fit the bore, and then drive it down one end of the pipe until the space will hold the quantity of phosphorus you wish to mix in the bath, minding not to split the barrel in driving in the plug. Make a plug of tin about $\frac{1}{8}$ in. thick to fit in the bore; now introduce your phosphorus into the space formed by the iron plug, and just tap the tin plug into the end of the barrel with a hammer. Stir it about in the molten metal; the tin plug soon melts, letting out the phosphorus in the bronze bath. Use bronze plugs for the end only.

In 1868, Montefiore and Künzel, of

Liége, Belgium, observed that the tin in bronze progressively decreases by oxidation during smelting, the tin oxide going partly into the slag and being partly dissolved in the molten metal, so that bronze originally composed of 10·10 per cent. tin and 89·90 copper, after the 4th melting contained only 8·52 tin and 91·48 copper. It was found that "poling" (stirring up the molten metal with a wooden stick) eliminated the oxide combined with copper, but had no effect on the tin oxide. Künzel then tried the introduction of a little phosphorus, or phosphuret of tin or copper, into the mass, with the desired result. Bars cast from the same crucible of metal under the three conditions named gave the following figures:—

Conditions of the Mass of Metal.	Resistance.		Lengthening until Rupture.
	Absolute Lb. per Square Inch.	Elastic Lb. per Square Inch.	
			per cent.
Old bronze	22,982	17,020	2·0
,, poled	24,922	17,709	2·8
,, deoxidized with phosphorus	33,916	19,300	6·8

Other experiments in phosphorizing alloys of copper, nickel, manganese, and iron, were not satisfactory; nor was that of using sodium instead of phosphorus as a deoxidizer. The action of phosphorus in bronze is (1) to eliminate the oxides, and (2) to make the tin capable of assuming crystalline structure, thus increasing the homogeneity of the alloy, and thereby its elasticity and absolute resistance. Among other properties, phosphor-bronze emits sparks under friction much less readily than gun-metal or copper; it is peculiarly adapted for friction-bearings; is easily rolled into sheets, and is very tough in that form; and oxidizes in sea-water at about one-third the rate of copper.

Platinum is capable of being united to most other metals, the alloys being as a rule more fusible than platinum itself. It occurs in nature in combination with a rare metal called *iridium*, with which it is often alloyed; the resulting metal is called *iridio-platinum*, and, though still malleable, is harder than platinum, and unattacked by aqua regia. It is also much less readily fusible than platinum itself, and is therefore likely to be largely used in place of this metal for the purpose of electric lighting by incandescence. Silver is hardened, but rendered brittle, by being alloyed with very small quantities of platinum.

Solders. — Alloys employed for joining metals together are termed "solders," and they are commonly divided into two classes: hard and soft solders. The former fuse only at a red heat, but soft solders fuse at comparatively low temperatures.

One of the most easily fusible metals is an alloy of 2 parts bismuth, 1 tin, and 1 lead; tin is the most fusible of these three metals, melting at 455° F. (235° C.), but this alloy melts at 199½° F. (93° C.), or a little below the boiling point of water. By diminishing the quantity of bismuth in the alloy, the point of fusion may be made to vary between 212° F. (100° C.) and 329° F. (200° C.), and thus it is an easy matter to form a solder which shall fuse at any required temperature between these limits, for electrical purposes, steam-boiler plugs, &c. The following are the best recipes for the common solders:— For *aluminium-bronze:* (*a*) 88·88 gold, 4·68 silver, 6·44 copper; (*b*) 54·4 gold,

27 silver, 18·6 copper. (*e*) Melt 20 parts of aluminium in a suitable crucible, and when in fusion add 80 of zinc. When the mixture is melted, cover the surface with some tallow, and maintain in quiet fusion for some time, stirring occasionally with an iron rod. Then pour into moulds. (*d*) 15 parts aluminium and 85 of zinc; (*e*) 12 aluminium and 88 zinc; (*f*) 8 aluminium and 92 zinc; all of these alloys are prepared as (*e*). The flux recommended consists of 3 parts copaiba balsam, 1 of Venetian turpentine, and a few drops of lemon-juice. The soldering-iron is dipped into this mixture.

For *brass-work:* (*a*) equal parts of copper and zinc; (*b*) for the finer kinds of work, 1 part silver, 8 copper, 8 zinc.

For *copper:* (*a*) 3 parts copper, 1 zinc; (*b*) 7 copper, 3 zinc, 2 tin.

Hard solder: 86·5 copper, 9·5 zinc, 4 tin.

Hard solder for gold: 18 parts 18 carat gold, 10 silver, 10 pure copper.

Hard silver solder: (*a*) 4 parts silver, 1 copper; (*b*) 2 silver, 1 brass wire; these are employed for fine work; the latter is the more readily fusible; (*c*) equal parts copper and coin silver; requires higher temperature than *b*, but will not "burn," is as fluid as water, and makes a far sounder joint.

Hard spelter solder: 2 parts copper; 1 zinc; this solder is used for iron-work, gun-metal, &c.

For *jewellers:* (*a*) 19 parts fine silver, 10 brass, 1 copper; (*b*) for joining gold, 24 parts gold, 2 silver, 1 copper.

Middling hard solder: 4 parts scraps of metal to be soldered, 1 zinc.

For *pewterers:* (*a*) 2 parts bismuth, 4 lead, 3 tin; (*b*) 1 bismuth, 1 lead, 2 tin; the latter is best applied to the rougher kinds of work.

For *sealing iron in stone:* 2 lead, 1 zinc.

For *sealing tops of canned goods:* 1¼ lb. lead, 2 lb. tin, 2 oz. bismuth; the lead is melted first, the tin added next, and finally the bismuth stirred in well just before pouring. This makes a soft solder, and the cans do not take much heat to open them.

Soft solder: 1 lead, 2 tin.

Soft solder for joining electrotype plates: 67 parts lead, 33 tin.

For *steel:* 19 parts silver, 3 copper, 1 zinc.

For *tinned iron:* 7 lead, 1 tin.

Specular Alloys.—These are employed for making metallic reflectors, requiring a true white colour, good lustre, and a hard, clean surface not easily tarnished or scratched. Fesquet gives a number of combinations, as follows:—

(*a*) 62 parts copper, 32 tin, 6 lead; (*b*) 80 copper, 10 lead, 10 antimony; (*c*) 66 to 63 copper, 33 to 27 tin; (*d*) 10 copper, 10 tin, 10 antimony, 50 lead; (*e*) 32 copper, 50 tin, 1 silver, 1 arsenic; (*f*) 90 steel, 10 nickel; (*g*) 50 palladium, 50 silver; (*h*) 60 platinum, 40 copper; (*i*) 50 platinum, 50 steel; (*j*) 50 platinum, 50 iron; (*k*) 10 platinum, 90 steel; (*l*) 20 platinum, 80 copper, 0·5 to 1 arsenic; (*m*) 60 platinum, 30 iron, 10 gold; (*n*) 50 gold, 50 zinc; (*o*) 50 steel, 50 rhodium; (*p*) 10 platinum, 90 iridium; (*q*) 29 tin, 19 lead; (*r*) 52 copper, 30 nickel, 12 zinc, 5 lead, 1 bismuth.

Tungsten Bronzes.—In the arts, tungsten bronzes of different colours are used, namely, golden-yellow, reddish-yellow, purple-red, and blue. The first two crystallize in forms resembling cubes, while the third is obtained partially in cubes and partially in amorphous pieces, and the last-named forms prismatic crystals. Other circumstances being equal, the yellow bronze is obtained from mixtures poor in acid, the other two from those containing more acid. But the colour is dependent not merely on the composition of the soda tungstate salt, but also on the amount of tin, and on the duration of the fusion; so that when much tin is used, and the fusion is prolonged, a yellow bronze is obtained from a very acid mixture, and, on the contrary, a salt that is but slightly acid, when fused only a short time and with very little tin, may yield a red or even a blue bronze.

A mixture of two molecules of soda tungstate and 1 of anhydrous tung-

stic acid, with tinfoil slowly added, and kept melted for 1 or 2 hours, will yield cubes ¼ in. long when about 4 oz. are melted, and they will produce a yellow or reddish-yellow bronze, the powder of which seems light brown, and when stirred up with water it imparts to the liquid the property of appearing of a fine blue colour by transmitted light.

The red bronze obtained from 10 parts soda carbonate, 70 soda tungstate, and 20 tinfoil yields, on pulverization, a powder that, stirred up in water, transmits green light.

According to J. Philipp, a blue bronze is always obtained if the fused mixture contains more than 3 molecules of tungstic acid to 1 of soda; if the fused product is boiled alternately with muriatic acid and with carbonate of soda, the result will be a considerable quantity of fine blue prismatic crystals, with which there are intermixed, in most cases, single red and yellow cubes.

Moreover, all the tungsten bronzes obtained by fusion with tin can also be prepared by electrolysis of fused acid tungstates, but the yield is so small that it is unprofitable. (*Ind. Zeit.*)

Type-metal.—This alloy, used for printers' type, is often composed of 6 parts lead, and 2 antimony. It is of a blackish-grey colour, and is softer than tin and copper, but a little harder than lead. Several of these alloys, having the following compositions by weight:—

Lead	86·21	80	75
Antimony ..	13·79	20	25
	100	100	100

have been submitted to a new examination by F. de Jussieu, who has published his results in a pamphlet of some scientific interest, printed at Autun. Every scientific metallurgist acquainted with the singular properties of precipitated metallic antimony, as published some years ago by Gore, will be prepared to expect many remarkable properties of that metal and its alloys, which as yet have been but imperfectly studied, though the metal itself, in a state of imperfect purity, has been known since the 15th century, when its powerful medicinal properties were first ascertained and employed by Basil Valentine and Paracelsus. The chief portion of de Jussieu's pamphlet is devoted to the experimental recognition and exposition of facts of interest to the purely scientific metallurgist, and especially in reference to the liquation and crystallization upon reduction of temperature of these alloys; but there are a few things intercalated which may prove of practical importance. Amongst these is the fact that those alloys of lead and antimony, whose constituents are the same in kind as common type-metal, are susceptible of assuming a high degree of hardness when rapidly cooled against a cold metallic surface, showing a perfect analogy with the property of hardening by chilling eminently possessed by certain cast-irons, but more or less shown by all known varieties of that metal. In the hands of the experimentalist well acquainted with the existing methods of casting stereotyped plates, De Jussieu's results may yet prove of considerable practical value. (*Engineer.*)

Fesquet gives the following combinations:—

Large type: (*a*) 10 lead, 2·5 copper; (*b*) 9 lead, 1 antimony, 0·5 arsenic; (*c*) 8 copper, 2 tin, 0·5 bismuth; (*d*) 2 copper, 2 tin, 2 bismuth; (*e*) 73 copper, 27 zinc; (*f*) 5 copper, 67 zinc, 25 tin, 3 nickel; (*g*) 12 tin, 16 zinc, 64 lead, 8 antimony.

Music plates: (*a*) 5 to 7·5 tin, 5 to 2·5 antimony; (*b*) 16 lead, 1 antimony; (*c*) 8 lead, 2 antimony, 1·5 tin; (*d*) 4 lead, 2 antimony, 1 zinc; (*e*) 7·5 lead, 2·5 antimony, 0·5 copper.

Printing type: 4 parts lead, 1 antimony.

Small type and Stereotypes: (*a*) 9 parts lead, 2 antimony, 2 bismuth; (*b*) 16 lead, 4 antimony, 5 tin. (*c*) For every 6 lb. of lead add 1 lb. antimony. The antimony should be broken into very small pieces, and thrown on the top of the lead when it is at red heat. The cheapest and simplest mode of making a stereotype metal is to melt old type, and to every 14 lb. add about

6 lb. of grocers' tea-chest lead. To prevent any smoke arising from the melting of tea-chest lead, it is necessary to melt it over an ordinary fire-place, for the purpose of cleansing it, which can be done by throwing in a small piece of tallow about the size of a nut, and stir it briskly with the ladle, when the impurities will rise to the surface, and can be skimmed off. In the mixing of lead and type-metal, see that there are no pieces of zinc amongst it, the least portion of which will spoil the whole of the other metal that is mixed with it. Zinc is of a bluish-white colour; its hue is intermediate between that of lead and tin. It takes about 80° more heat than lead to bring it into fusion; therefore should any metal float on the top of the lead, do not try to mix it, but immediately take it off with the ladle.

Miscellaneous.—The following is a table of the proportions of the various metals in the alloys most commonly employed in the arts and manufactures. The term "parts" means parts by weight. The abbreviations are: Cu, copper; Zn, zinc; Sn, tin; Pb, lead; Sb, antimony; P, phosphorus; As, arsenic; Ni, nickel.

Description.	Cu.	Zn.	Sn.	Pb.	Sb.	P.	As.	Ni.
Metal for frictional parts of locomotives (extremelyhard)	87	5	8	..	..	..	..	..
Bearings of carriages	97	3	..	..	..	..	..	..
Bearings of driving wheels, also for steam-engine whistles giving a clear sound	80	2	18	..	..	..	..	..
Steam-engine whistles giving a deep sound	81	2	17	..	..	..	..	..
Cross-heads of connecting-rods	82	2	16	..	..	..	..	..
Cylinders of pumps, valve-boxes, and taps	88	2	10	..	..	..	..	..
Eccentric collars	84	2	14	..	..	..	..	..
Bearings of axles and trunnions; eccentric collars	84	2	14	..	..	..	..	..
	85	2	13	..	..	..	..	..
	84	7	9	..	..	..	..	..
	68	4	28	..	..	..	..	..
Pistons of locomotives	88	9	3	..	..	..	..	..
	84	8·4	2·9	4·7	..	..	..	..
Axle-boxes	88	2	10	..	..	..	..	..
Mathematical instruments, arms of balances	90	2	8	..	..	..	..	..
Machinery, bearings, &c.	67	..	14	19	..	..	..	..
Steam-engine whistles	30	..	18	..	2	..	..	..
Metal to withstand friction (Stephenson)	79	5	8	8	..	..	..	..
Rivets	64	24·6	3	9	..	..	..	..
Metal for coffins	15	..	40	45	..	..	..	..
Metal to withstand friction	2	..	72	..	26	..	..	..
Cylinders of pumps	7	72	21	..	..	..	..	..
Metal for bearings of locomotives	2	..	90	..	8	..	..	..
White brittle metal (for buttons, &c.)	10	6	20	..	64	..	..	..
Imitation silver	64	..	3	..	..	..	..	..
Pinchbeck	5	1	..	..	..	..	..	..
Tombac	16	1	1	..	..	..	..	..
Red tombac	10	1	..	..	..	..	..	..

Description.	Cu.	Zn.	Sn.	Pb.	Sb.	P.	As.	Ni.
Specially adapted for bearings ..	83	..	15·5	..	1·5	..	..	..
For bearings and valves	83·25	..	7	9	..	·75	..	..
Electrotype "backing metal"	..	..	4	91	5	..	..	..
Stereotype metal for paper process	..	..	..	88	12	..	..	..
„ „ for plaster process	..	..	..	82	18	..	..	..
Bullet metal	..	..	..	92	..	..	2	..
Malleable brass plate	67	33	..	·5	..	..	..	..
Pin wire	67	33	·5	·5	..	..	..	..
Jemmapes brass	64·6	33·7	·2	1·5	..	..	..	..
Similor for gilding	92·7	4·6	2·7	..	..	..	..	..
Maillechort for rolling	60	20	..	..	..	..	..	20
„ first quality	8	3	..	..	..	..	..	4
White similor	7	..	..	..	..	..	·5	..
For stopcock seats	..	..	86	..	14	..	..	..
„ plugs	..	..	80	..	20	..	..	..
For keys of flutes, &c.	..	..	..	20	40	..	..	..
Hard tin	..	..	1	..	0·5	..	..	..
White tombac	75	..	25	..	..	..	..	..
Vogel's alloy for polishing steel ..	8	1	2	1	..	..	..	..
Rompel's anti-friction metal	62	10	10	18	..	..	..	..
Arguzoid, a tough alloy superior to brass	56	23	4	3½	..	..	..	13½

The proportions of the several ingredients in the various alloys given above must be regarded as only approximative in many cases. Every manufacturer adopts the proportions which experience has taught him to be the most suitable for the purposes for which the alloy will be used, or perhaps, in some instances, which accident or caprice first led him to make use of. Half a dozen samples of that variety of pewter known as Britannia metal, from as many different manufacturers, would probably prove widely different in their composition, though similar in appearance, and applicable to the same uses. The same remark holds good of such alloys as pinchbeck, tombac, Mannheim gold, and some others. More than this, even the products of the same manufactory may vary considerably in composition at different times, when these products are not required to possess in a high degree any given quality. It is, therefore, not surprising that the proportions published in many works are so different and contradictory. Thus we have, for example, one acknowledged authority giving the composition of Britannia metal as equal parts of brass, tin, antimony, and bismuth; while another gives the composition as 150 parts of tin, 3 parts of copper, and 10 parts of antimony, omitting the bismuth altogether. It would be easy to find a third authority giving a composition of this alloy widely different from the above two. From out of this chaos it is impossible to evolve anything like order, or to give information that shall not be at variance with all that has preceded it from sources acknowledged to be trustworthy. Hence the recipes given must be regarded as having only an approximate value generally, though for the cases in view they are exact, *i.e.*, they are the proportions which have been actually adopted in practice. Many of them have been ascertained by analysis of the finished product, while others have been obtained from sources that are worthy of confidence.

A number of ancient alloys examined by W. Flight showed the following com-

positions:—(1) Bactrian coins, about 230 B.C., contained 77 per cent. copper, 20 nickel, and smaller quantities of cobalt and iron. (2) Square Indian coins, 500 B.C., 89 per cent. silver, 4 copper, 4 lead, with silver chloride, gold, and graphite. (3) A figure of Buddha, 57 per cent. silver, 4 silver chloride, 37 copper, with gold and graphite. (4) Boxes or bowls of Bidrai ware, Secunderabad, India, 94 per cent. zinc, 4 copper, 1½ lead, into the surface of which thin sheet silver is inlaid. (8) Double hook of bronze found in an air passage of the Great Pyramid, 99½ per cent. copper. (9) Bronze figures brought from Egypt by John Dixon, supposed to be of Ptolemaic origin: a figure of Isis, 68·4 per cent. copper, 4·7 iron, 22·7 lead, 1·5 arsenic, 0·9 tin, with traces of nickel and antimony; another bronze, 82·2 per cent. copper, 15·8 lead, 2 tin. (13) Various Cypriote, Roman, and Greek bronzes, 78 to 87 per cent. copper, 8·5 to 10·9 tin, and 1·5 to 9 lead. (14) Inca pin, from a mummy at Arica, 82 per cent. silver, 1·4 silver chloride, 16·1 copper. (15) Bronze bar from temple in Bolivia, 93·2 per cent. copper, 6·5 tin.

Kalischer, of Berlin, recently made an analysis of four Japanese alloys, with the following results:—

	a	*b*
Copper	95·77	51·10
Silver	0·08	48·93
Gold	4·16	0·12
	c	*d*
Copper	76·60	76·53
Lead	11·88	12·29
Zinc	6·53	6·68
Tin	4·38	4·36
Iron	0·47	0·33

The first, which contained much gold, had a light-red colour, with a bluish-black, lustrous patina on one side. The second, which contained silver, had a grey, almost silver-white colour, with a slight shade of yellow. *c* and *d* resembled brass in colour, and were, as the figures show, almost identical, representing a peculiar kind of bronze. Externally they were exactly alike, except that one had a fine crust outside which gave it a duller look than the metal itself. They differ from bronze in having so much lead in them, and the amount of zinc is also higher.

H. Morin published analyses of some Chinese and Japanese bronze exhibited at Paris in 1867; like *c* and *d* above, they are distinguished by the large percentage of lead, which he found to vary between 9·9 and 20·31 per cent., while the zinc fluctuated from 0·5 to 6·0 per cent. To the large amount of lead Morin attributes the black patina which mostly characterises these bronzes. Gristofle and Bouilhet, on the one hand, confirm this view, and, on the other, prove that patina of different colours may be produced by chemical means without having recourse to bronze containing a large quantity of lead, which, as Morin himself states, is difficult to use on account of its brittleness. Morin's analyses show that in other respects the bronzes he examined bear no relation to those analysed by Kalischer.

In 1866 R. Pumpelly published the composition of a number of Japanese alloys, which showed the greatest conformity with the above, especially the two first mentioned. A native worker in metals allowed Pumpelly a glance into the preparation of the metals, which is generally kept secret, and he described, under the name of *shaku*, alloys of copper and gold in which the quantity of gold varied from 1 to 10 per cent. They have a bluish-black patina, which is produced by boiling the metal or the object made of it in a solution of copper sulphate, alum, and verdigris, which removes some of the copper and exposes a thin film of gold. The action of light upon this produces the bluish-black colour, the intensity of which increases with the quantity of gold. This group can be reckoned with alloy *a* above. *Gin-shi-bui-chi* is an alloy of silver and copper, in which the amount of silver varies between 30 and 50 per cent. When boiled in the above solution, the alloy acquires a grey colour much admired by the Japanese. Alloy *b* belongs to this group. The name of *kara-kane* is given to a sort of bell-metal,

consisting of copper, zinc, tin, and lead, and having some resemblance to alloys *c* and *d*.

Maumené furnishes analyses of Japanese bronzes sent home in 1875 from public monuments, temples, and works of art. The alloys are granular in texture, and readily take a good polish, bringing out the true colour of the metal over large surfaces. The predominating tint is purple where much antimony is present, red where iron is the chief ingredient. These alloys have evidently been prepared with unrefined minerals. In Maumené's opinion they are to be regarded as results of the admixture of copper pyrites and antimonial galena with blende. In some, the calcination appears to have been imperfect, as shown by the sulphur present in *b*:—

	a	*b*	*c*	*d*
Copper	86·38	80·91	88·70	92·07
Pewter	1·94	7·55	2·58	1·04
Antimony	1·61	0·44	0·10	„
Lead ..	5·68	5·33	3·54	„
Zinc ..	3·36	3·08	3·71	2·65
Iron ..	0·67	1·43	1·07	3 64
Manganese	„	Trace.	„	„
Silica ..	0·10	0·16	0·09	0·04
Sulphur	„	0·31	„	„
Loss ..	0·26	0·74	0·21	0·56
	100·00	100·00	100·00	100·00

The Japanese word corresponding to the English "bronze" is *karakane*, which means "Chinese metal"; whereas the brass alloys are called *shin-chu*. The spelter used for the latter is imported. The industry of bronze-casting is of very ancient origin; at first foreign metal, imported either from China or Corea, must have been used, as Japanese copper has only been produced since the beginning of the 8th century; by that time, however, the industry of bronze-casting had already reached a certain state of perfection. This is shown by the fact that the priest Giyoki, who lived about this time, proposed the erection of a monster bronze statue of Buddha, which was carried into effect. There were formerly 3 of these statues in Japan, each about 50 ft. in height. Other specimens of large bronze-castings are the famous bells of Nara, Kiyoto, Nikko, Shiba in Tokio, and others, which have an average height of 15 ft. and are more than 10 ft. in diameter. Statues of all sizes, bells, vases, water-basins, candlesticks, incense-burners, lanterns, &c., have been manufactured in large quantities for temples and their approaches. Portrait-statues, like the monuments erected in foreign countries to honour the memory of celebrated men, have never been made in Japan. As articles for household uses, may be mentioned fire-pots, water-pots, flower-vases and basins in which miniature gardens are made, perfume-burners, pencil-cases, small water-pots of fanciful shapes for writing-boxes, paper-weights, and small figures representing divinities. These bronze-castings are either made in the simple and severe style of the old celebrated Chinese bronzes, or else are specimens of the peculiar character of Japanese art, which chooses its subjects from natural life, either combining them with lively scenes showing a great deal of humour, together with the most minute copying of nature, or else using them to produce some artistical effect. The bronze is cast in clay moulds formed upon models made of a mixture of wax and resin, which is melted out from the finished mould previous to pouring the metal in. The artist who makes the model generally does the casting himself, and in most cases the workshops consist only of the master's family and 2 or 3 assistants. The melting furnaces are of exceedingly small dimensions, and generally made of an iron kettle lined with clay. After casting, the pattern is carefully corrected and worked out by chiselling, but the best bronze-casters prepare the model, the mould, and the alloy in such a way as to produce castings which need no further correcting or finishing. In some cases also the whole pattern is produced merely with the chisel working upon a smooth surface; this, for instance, is frequently done in the provinces of Kaga and Yechiu, which are very important cen-

tres of the bronze industry. The bronzing of the pieces is done in many different ways, each manufacturer having his own particular process, which he modifies according to the composition of the alloy and the colour he wishes to produce. The chemicals used for this purpose are very few in number, and limited to vinegar, copper sulphate, and verdigris as the principal substances; other materials, used less frequently, consist of iron sulphate, red oxide of iron, and lacquer. It may be added as a peculiarity, that an infusion of *Eryanthus tinctorius* is also made use of in the bronzing process.

The ornamentation of bronze castings is not only produced by relief patterns moulded or chiselled, but also by inlaying the objects with gold, silver, or with a different alloy. This kind of workmanship is called *zogan*, and is principally carried on in the provinces of Kaga and Yechiu. The process by which the inlaid work is effected differs according to the nature of the material on which it is produced. Sometimes the design is hollowed out to a certain depth with a graver or chisel, and the ornamenting metal, silver, gold, &c., generally in the shape of threads, is laid into the hollow spaces and hammered over, should the alloy be soft enough; the edges of these grooves are first slightly driven up, so that when the silver or gold has been laid in, they can be easily hammered down again, so as to prevent the inlaid metal from getting loose. Or else the surface is merely covered in the required places with a narrow network of lines by means of filing, and the thin gold or silver leaf fastened on to this rough surface by hammering. This last process is the one used mostly for inlaid iron-work. It is also said that the design is often produced by a process very similar to that of the so-called *nie'llo*; only instead of the black sulphuretted silver and copper, a more easily fusible alloy is used. Inlaid work of the above kind is principally made in Kaga and Yechiu, at Kanasawa and Takaoko, where the alloy used for the bronze casting is mostly composed of copper, tin, zinc, and lead. In addition to the castings, the repoussé work should be mentioned, by which mostly small metallic ornaments for swords, tobacco pouches, &c., and also larger pieces, such as tea-pots, scent-burners, vases, &c., are produced; the inlaying of this kind of ware is sometimes of extraordinary delicacy and beauty. The dark blue colour shown by a great number of smaller pieces is that of the *shakudo*, composed of copper, and 3 or 4 per cent. of gold. Finally, attention should be called to the so-called *moku-me*, a word which might be rendered by "veins of the wood." The metal-work designated by this name presents a sort of damask pattern composed of variously-coloured metals, chiefly white silver, red copper, and a dark blue alloy. Pieces of this very difficult sort of workmanship are produced by overlaying and soldering together a certain number of plates of the said metals or alloys, by hammering, kneading, resoldering, filling up the hollow spaces with new metal, and repeating these operations many times; finally, when stretched out into a thin sheet, this composition shows the aforesaid pattern all composed of veins of the different metals that have been made use of. (*Jl. Ap. Sci.*)

Ludwig has made a number of analyses of ancient bronze implements, of great hardness, with the following results:—

	Copper.	Tin.	Nickel.	Iron.	Phos.
(1)	87·25	13·08	0·38	trace	0·250
(2)	83·65	15·99	0·63	,,	0·540
(3)	85·05	14·38	trace	,,	0·106
(4)	88·06	11·76	,,	,,	0·027

Specimen No. 1 was a fragment of an axe from Maiersdorf. The metal was tenacious and bright yellow; hardness equal to that of apatite. No. 2: an axe from Linburg; reddish golden-yellow; tenacious and hardly scratched by felspar. No. 3: fragment of a sword from Steier; the metal was reddish-yellow, solid and tenacious, and not easily scratched by quartz. No. 4: a chisel from Peschiera; deep yellow, and containing a trace of cobalt. Neither

zinc nor lead was found in any of the specimens. (*Mech. Eng.*)

Reichardt gives the following analysis of a sample of bronze found near Dantzig, and constituting fragments of a ring or other ornament:—

Tin	5·591
Silver	Trace.
Iron	0·363
Lead	0·041
Zinc	1·388
Copper	92·638
	100·021

This may be compared with others, as under:—

a. Bronze rings from Gallic sepulchral tumuli (Kopp).

b. Bronze from the bone caves of Périgord (Terreil).

c. Celtic bronze armlets from Aboyne (Church).

d. Bronze statue found at Brescia (Arnaudes).

e. Bronze from Messer, Siberia (Struve).

f. Celtic arrow heads (Olivier).

	a		*b*
Copper	89·71	84·76	85·98
Tin	7·78	13·31	12·64
Zinc	—	—	0·51
Lead	1·29	1·80	1·09
Iron	0·52	Trace.	Trace.

	c		*d*
Copper	86·49	88·19	80·70
Tin	6·76	3·64	9·44
Zinc	1·44	9·13	1·92
Lead	4·41	—	7·68

	e		*f*
Copper	99·0	88·67	70·30
Tin	0·32	10·10	24·53
Lead	—	—	5·20
Iron	0·34	0·28	—

It thus appears that there are great differences in the composition of antique bronze even among different specimens found at the same place, the quantities of tin and of lead varying greatly.

Inoxidizable Alloys.—A new alloy, which resembles silver, and is very ductile and malleable, is composed of 65 parts iron, 23 of nickel, 4 of tungsten, 5 of aluminium, and 5 of copper. The iron and the tungsten are melted together and then granulated, and the water into which the mixture is poured for this purpose must contain 1 lb. of slaked lime, and the same quantity of potash, to every gallon. The product formed by the fusion of the nickel, the copper, and the aluminium, is also granulated in water containing the same proportion of lime and potash; and during the melting the metals in the 2 crucibles must be kept covered with a flux made of 2 parts borax and 2 of saltpetre. A piece of soda or potash, weighing about $\frac{1}{250}$ of the whole mass, is put into the crucible containing the copper, nickel, and aluminium, in order to prevent the oxidation of the last-named metal; and, to prevent the same action taking place with the copper, a small piece of charcoal is added. It is advisable before the operation of granulation to well stir the contents of the 2 crucibles. The granulated metals are dried, melted in the proportion given above, well shaken, and then run into bars. The metal is called "sideraphthite." Another formula for its preparation is: 66 parts iron, 23 nickel, 5 copper, and 4 tungsten.

Lemarquand's inoxidizable alloy contains 750 copper, 140 nickel, 20 black oxide of cobalt, 18 rod tin, 72 pure zinc.

Marlie's consists of 10 parts iron, 35 nickel, 25 brass, 20 tin, 10 zinc, plunged while hot into a mixture of 30 parts sulphuric acid, 10 nitric acid, 5 hydrochloric acid, 25 water.

Soft Alloy.—This alloy will adhere so firmly to metallic, glass, and porcelain surfaces, that it can be used as a solder, and is invaluable when the articles to be soldered are of such a nature that they cannot bear a high degree of temperature. It consists of finely pulverized copper or copper-dust, and is obtained by precipitating copper from the sulphate by means of metallic zinc: 20, 30, or 36 parts of this copper-dust, according to the hardness desired, are placed in a cast-iron or porcelain-lined

mortar, and well mixed with some sulphuric acid having a specific gravity of 1·85. Add to the paste thus formed 70 parts (by weight) of mercury, constantly stirring. When thoroughly mixed, the amalgam must be carefully rinsed in warm water to remove the acid, then laid aside to cool. In 10 or 12 hours it will be hard enough to scratch tin. When it is to be used, it should be heated to a temperature of 707° F. (375° C.), when it becomes as soft as wax by kneading it in an iron mortar. In this ductile state it can be spread upon any surface, to which, as it cools and hardens, it adheres very tenaciously.

Alloy for Small Articles.—This alloy melts at a lower degree of temperature than the one just described, and is very hard without being brittle. It consists of 6 parts bismuth, 3 zinc, and 13 lead. The 3 metals, after having been well melted and stirred together, should be poured into another melting-pot and melted again. This alloy cools with remarkably clear-cut edges, and if the articles made of it are dipped in dilute nitric acid, then rinsed in clear water, and polished with a woollen rag, the raised parts of the surface will have a fine polish, while the sunken parts will have a dark-grey, antique appearance, which forms a pretty contrast. The proportions of the different metals, dividing the alloy into 100 parts, are: 27·27 bismuth, 59·09 lead, 13·64 zinc.

Alloy for Small Castings.—Contains 6 parts bismuth, 3 tin, 13 lead. This alloy should be melted, run into bars, and laid aside till wanted, when it should be remelted. An alloy of 3 parts bismuth, 1 tin, 1 lead, for small castings, is harder, and yet it is not brittle. It can be finished with a contrasting surface of bright polish and dark grey, if it is washed in nitric acid, well diluted, rinsed, and polished with a woollen rag, as described in the alloy for small articles given above.

White Alloy.—This compound can be turned, filed, and bored; does not adhere to the mould, and will retain its polish a long time after exposure to the air. Contains 10 cast-iron, 10 copper, 80 zinc.

Alloys for Medals, Coins, &c.—Kraft's alloy: melting point, 219° F. (104° C.); contains 5 bismuth, 2 lead, 1 tin.

Homberg's alloy: melting point, 251½° F. (122° C.); contains 3 bismuth, 3 lead, 3 tin.

Rose's alloy: melting point, 199° F. (93° C.); contains 2 bismuth, 2 lead, 2 tin.

Amalgam for Coating Plastic Castings.—1 part tin, 1 mercury, 1 bismuth. The mercury is mixed with the white of an egg, and added to the tin and bismuth when they are thoroughly melted and blended. The alloy while still hot forms a pasty liquid, which should be applied with a brush. (Güttier.)

Anti-friction Alloys.—When the so-called "anti-friction alloys," or "white metals," were introduced, reports as to their value soon made their appearance, and one of the most important was that of Nozo, the engineer of the repairing shops on the Northern Railroad of France. Nozo experimented with Grafton's, Vaucher's, Detourbet's, and other metals, and he arrived at the conclusion that the "white metals," whether for whole journals or their linings, might be advantageously employed in machinery revolving with a small velocity, or with an average velocity and small strain; but that they were not suited to the rolling stock of railways, in which the strains and the velocity are such as to rapidly wear all metals not hard enough to resist energetic friction. The term "white metal" is applied to all alloys in which zinc, tin, or lead is in sufficient proportion to impart a white colour, and a reference to the list on p. 34 will show that the number of white alloys is great. Babbit's metal and Parson's white brass are the two best known of these, but it may be doubted whether any hard and fast line as to the proportions of the respective ingredients can be drawn. On the contrary, it would seem that brasses suitable for various kinds of work may be made almost haphazard, with just as great a probability of obtaining a good result

as if the utmost care were taken in weighing the components of the alloy, and adding them in the proper order in the crucible. A good white metal for lining journal boxes, pillow-blocks, &c., is made of—

Copper	4 parts
Tin	96 ,,
Antimony	8 ,,

In this the tin is in excess, and the alloy is prepared in a roundabout way: 12 parts copper are first melted, and then 36 of tin are added; 24 of antimony are put in, and then 36 of tin, the temperature being lowered as soon as the copper is melted, in order not to oxidize the tin and antimony, the surface of the bath being protected from contact with the air. The alloy thus made is subsequently remelted in the proportion of 50 parts alloy to 100 tin. For small journals, where the friction is not great, both the copper and antimony may be doubled in quantity. An alloy of 1 part copper, 50 tin, and 5 antimony, has a greasy feel, and is good for machines not overworked; but a better metal for lining bearings subjected to rapid, not heavy friction, is made of 85 parts lead, 15 antimony. Vaucher's alloy is composed mainly of zinc and tin, with small quantities of lead and antimony, the last being melted separately. Brasses for locomotive bearings are usually made of—

Copper	64 parts
Tin	7 ,,
Zinc	1 ,,

But experiments recently made in the United States have yielded very good results with white metal for the journal-box linings of engines, coaches, and waggons. Babbitt's metal—the composition of which is variously stated—resembles the alloy first specified, and may be described as a tin alloy, 10 parts of that metal being used in conjunction with 1 each of copper and antimony. In recent years, phosphor bronze and manganese bronze have established a good reputation, and latterly cadmium has attracted some attention as an ingredient in alloys for bearings. It fuses below a red heat, and volatilizes so readily at the ordinary temperatures necessary for making alloys, that great difficulty has been experienced in using it as an ingredient. It is malleable and ductile, is harder and more tenacious than tin, but soils paper as lead does when it is rubbed over it. Possibly this property has attracted inventors to it, as the fine particles thus removed on slight friction would probably produce a highly smooth surface on a bearing made of an alloy containing cadmium. In Lechesne's new white metal, the novel feature is the use of cadmium. The proportions preferred are—

Copper	650 parts
Nickel	275 ,,
Cadmium	50 ,,
Zinc and Tin	25 ,,

On different lines of railway, and in various countries, a very large number of alloys have been tried for bearings. Thus, where the freight is light, bearings made of an alloy of lead and antimony have been found to give good results—the life of the journal being prolonged at the expense of the bearing, and with an increased consumption of lubricant. Alloys of tin and copper have been tried; but, except in some few proportions, they are too hard; though when the tin preponderates and there is an addition of antimony, a good bearing is obtained, but at too high a price. Bearings of white metal, and of an alloy of antimony and lead, possess the advantage that they are easily replaced; but unless the supply of lubricant is kept up, they soon wear out, and the latter rapidly fuse if the journal becomes heated. White metal bearings, with the copper and antimony preponderating, are too hard, too brittle, and break under heavy loads; while, if the tin is in excess, and they are subjected to great pressure, they soon wear out of shape. Dr. Künzel, whose name is well known in connection with phosphor-bronze, has made many experiments on bearings, and concludes that for a bearing to possess all the required qualities it should be heterogeneous in constitution, and that its skeleton, so to speak, should be made of a metal as tenacious as

possible, the hardness of which is nearly equal to that of the journal, so as to enable it to resist the shocks to which it is subjected without changing its shape. The interstices or pores of the skeleton should contain a soft metal. The final result of Dr. Künzel's investigations was the invention of his patented alloy (see p. 31), which consists of phosphor-bronze, with certain quantities of lead and tin added to form the soft alloy for filling the pores. By varying the proportions of the ingredients, and by adding or omitting the proportion of zinc, the hardness of the bearing may be adapted to that of the journal. (*Eng. Mech.*)

Aich, or Gedye's Metal.—This is an alloy of zinc and copper in nearly the same proportions as in Muntz's metal, but it contains also a little iron, thus :—

Copper	60·0
Zinc	38·2
Iron	1·8

It is very malleable at a red heat, and may be hammered, rolled, drawn into wire, or readily cast. It has been employed in Austria for casting cannon, and some Chinese cannon consist of a similar alloy.

Sterro-metal.—This is a very strong and elastic alloy used by Austrian engineers for hydraulic press pumps. It contains copper, zinc, iron and tin, in the following proportions :—

Copper	55 to 60
Zinc	34 ,, 44
Iron	2 ,, 4
Tin	1 ,, 2

Good specimens offer far more resistance than gun-metal to transverse fracture, and cost only $\frac{2}{3}$ the price. It is said to have been discovered in an attempt to employ, for the manufacture of brass, the alloy of iron and zinc found at the bottom of the zinc-pots in making galvanized iron.

Bismuth Bronze.—A new metallic alloy, which the inventor calls bismuth bronze, has been recently introduced by James Webster, of Solihull, as specially suitable for use in sea-water, for telegraph and music wires, and for domestic articles. The composition varies slightly with the purpose for which the bronze is to be used, but in all cases the proportion of bismuth is very small. For a hard alloy, he takes 1 part bismuth and 16 of tin, and having melted them, mixes them thoroughly as a separate or preliminary alloy. For a hard bismuth bronze he then takes 69 parts copper, 21 spelter, 9 nickel, and 1 of the bismuth tin alloy. The metals are melted in a furnace or crucible, thoroughly mixed, and run into moulds for future use. This bronze is hard, tough, and sonorous; it may be used in the manufacture of screw-propeller blades, shafts, tubes, and other appliances employed partially or constantly in sea-water, being specially suited to withstand the destructive action of salt-water. In consequence of its toughness, it is well suited for telegraph wires and other purposes where much strain has to be borne. From its sonorous quality, it is well adapted for piano and other music wires. For domestic utensils, and other articles generally exposed to atmospheric influence, the composition is 1 part bismuth, 1 aluminium, and 15 tin, melted together to form the separate or preliminary alloy, which is added in the proportion of 1 per cent. to the above described alloy of copper, spelter, and nickel. The resulting bronze forms a durable, bright, and hard alloy suited for the manufacture of spoons, forks, knives, dish-covers, kettles, teapots, jugs, and numerous other utensils. These alloys are said to resist oxidation, to polish well and easily, and to keep their colour well.

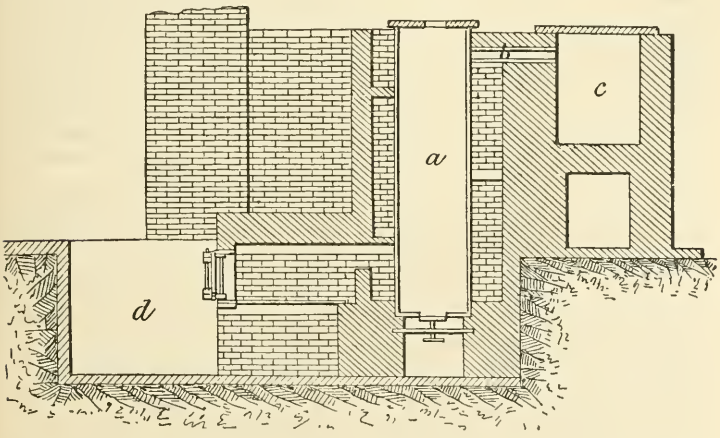
ALUMINIUM.—This metal possesses properties which render it one of the most useful yet discovered, and the only bar to its greater employment has hitherto been its high price. There is an immediate prospect of this being enormously reduced by Webster's process, described below. While being very malleable and ductile, aluminium ranks second only to steel in tenacity; it is highly sonorous, 4 times lighter than silver, non-volatile at very high temperatures, conducts heat and electricity as well as silver, is inoxidizable in the

air even at a red heat, is not acted upon by water, sulphuretted hydrogen, or ammonium sulphide, resists concentrated nitric acid and dilute sulphuric acid, and forms alloys (see p. 11) of considerable value.

The present method of manufacture consists in heating to redness a mixture of the double chloride of aluminium and sodium, or the double fluoride of aluminium and sodium (cryolite) with metallic sodium, by which sodium chloride is formed and metallic aluminium is separated. On the large scale, 10 parts of the double chloride, 5 of cryolite, and 2 of sodium are placed in a reverberatory furnace; immediately action has ensued, the fused metal and slag (consisting of common salt and aluminium fluoride) are run out, and a new quantity of the previous mixture is introduced. The current method of manufacturing aluminium was described at some length by J. L. Bell, at the British Association meeting of 1863 (see *Soc. Arts Jl.* xi. 769).

In making large quantities from the mineral bauxite $(AlFe)_2O_3H_4$, containing about 50 per cent. alumina and 25 iron oxide, the process is as follows: The mineral is pulverized, and the powder is mixed with soda and heated in a reverberatory furnace, when sodium aluminate forms; the mass is withdrawn from the furnace, and treated with water, which dissolves the sodium aluminate; the clear solution is decomposed by passing a current of carbonic acid gas through it, when sodium carbonate forms, and alumina is precipitated; when the reaction is complete, the whole is placed in linen filters and well washed, whereby the sodium carbonate is removed, and leaves the alumina behind in a pulverulent rather than gelatinous condition; when dry, it forms a pure white powder. To convert this into aluminium-sodium chloride, it is mixed with salt and coal-dust, and formed into balls, which are rapidly dried, and transferred to upright fire-clay retorts *a*, arranged in a furnace *d*,

FIG. 5.



as shown in Fig. 5; the heat is gradually increased till it reaches whiteness, when chlorine gas is introduced at the bottom of the retort; the aluminium-sodium chloride distils off, and passes by a tube *b* into the fire-clay chamber *c*, where it deposits, the carbonic oxide and excess of chlorine being conducted by a

pipe to the chimney. The double chloride has next to be decomposed by metallic sodium; with this object, it is mixed with sodium and some cryolite, the latter serving as a flux; the quantities taken are 100 lb. of the double chloride, 35 lb. sodium, and 40 lb. cryolite; the operation is conducted on the sole of a reverberatory furnace by a gradually increased heat; the reduced metal collects on the bottom, and is run into iron moulds. It always contains some iron and silica. The cost of manufacture for about 4000 lb. of aluminium in 1872 is thus stated:—

(*a*) Manufacture of the double chloride.

		per cwt.	*d.*
Anhydrous alumina	0·59 lb. at	34*s.* 8*d.*	2¼
Manganese ore * ..	3·74 lb. at	4*s.* 9½*d.*	2¾
Hydrochloric acid *	15·72 lb. at	1*s.* 2*d.*	2¾
Coal	25·78 lb. at	0*s.* 7*d.*	1½
Wages			1
Wear and tear			1½
Cost of 1 lb.			10¾

* To form the chlorine.

(*b*) Manufacture of metallic aluminium.

	s.	*d.*
Sodium, 3·44 lb. at 4*s.* 7*d.* per lb. ..	16	0
Double chloride, 10·04 lb. at 10¾*d.* per lb.	9	0
Cryolite, 3·87 lb. at 2*s.* 7*d.* per cwt...	0	10
Coal, 29·17 lb. at 7*d.* per cwt.	0	2
Wages	0	9
Wear and tear	0	4
Cost of 1 lb.	27	1

(Wurtz.)

Webster's new process, before alluded to, is as follows:—A given quantity of alum and pitch, which are first finely ground, are mixed together and placed in a calcining furnace, by which means 38 per cent. of water is driven out, leaving the sulphur, potash, and alumina with oxide of iron. The calcined mixture is then put into vertical retorts, and steam and air are forced through, which leaves a residue of potash and alumina only. This residue is afterward placed in a vat filled with warm water, which is heated with steam. The potash is thus leached out, and the alumina left as a deposit. The potash liquor is then run off and boiled down, while the alumina precipitate is collected in sacks and dried. It is then ready for making chloride of aluminium. The alumina deposit thus obtained contains about 84 per cent. of pure alumina, while that which is obtained by the old process of precipitation has only 65 per cent. Jones, the Wolverhampton borough analyst, certifies that the constituents of Webster's alumina deposit are as follows:—Alumina, 84·10; sulphate of zinc, 2·68; silica, 7·40; water, 4·20; alkaline salts, 1·62. In order to complete the process and convert it into aluminium, the aluminium chloride is treated with sodium, in order to withdraw the metal. The operations are completed in a few days instead of 9 months, and the product costs only about 100*l.* per ton instead of 1000*l.* The sources of raw material are inexhaustible and everywhere distributed. Webster also claims to have found ways to solder and weld the metal.

To ascertain fully the mechanical properties of this metal, a bar of aluminium, 3 ft. long and ¼ in. square, was obtained, and different parts of this bar were subjected to tests for tension, compression, transverse strain, modulus of elasticity, elastic range, and ductility. The experiments were carefully carried out under the direction of Prof. Kennedy, with his testing machine, at the London University, and the results are given in the table appended.

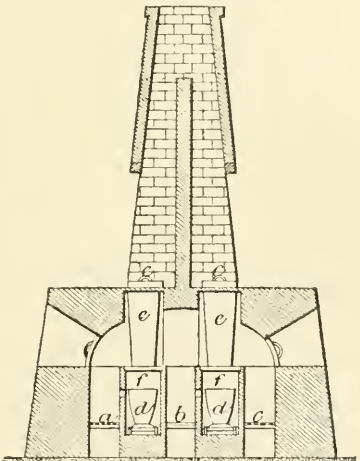
It will be seen that the weight of 1 cub. in. is ·0972 lb., showing a specific gravity of 2·688, and that its ultimate tensile strength is about 12 tons per sq. in. The range of elasticity is large, the extension at the yielding point being $\frac{1}{20}$ of its length. The modulus of elasticity is 10,000. The ductility of samples 2 in. long was only ⅔ per cent., but it is probable that the metal could be improved in this respect. Taking the tensile strength of the metal in relation to its weight, it shows a high mechanical value. Its characteristics in this respect, as compared with those of other well-known metals, are shown in the following summary:—

Name of Metal.	Weight of 1 cub. ft. in lb.	Tensile strength per sq. in. in lb.	Length of bar just capable of bearing its own weight.
Cast-iron . . .	444	16,500	5,351
Bronze	525	36,000	9,893
Wrought-iron .	480	50,000	15,000
Steel of 35 tons per in. . . .	490	78,000	23,040
Aluminium . .	168	26,880	23,040

It thus appears that, taking the strength of aluminium in relation to its weight, it possesses a mechanical value about equal to steel of 35 tons per in. Its mechanical properties point to its suitability for those cases where strength, combined with lightness and a great range of elastic action, is required. The elastic range is about 3 times that of steel, and about 5 times that of wrought-iron. It has become somewhat common in Paris to make the frames of opera-glasses and telescopes of aluminium. But the most favourable use apparent for this curious metal, by reason of its low specific gravity, is the making of beams for balances: aluminium-bronze beams have been made for several years past, but, as far as lightness is concerned, they have scarcely any advantage over brass. Several reasons are given for the small amount of favour with which aluminium is regarded by mathematical instrument makers. First of all, there is the consideration of price; then the methods of working it are not everywhere understood; and, further, no one knows how to cast it. Molten aluminium attacks the common earthen crucible, reduces silicon from it, and becomes grey and brittle. This inconvenience, however, has been overcome by the use of lime crucibles, or by lining the earthy crucible with carbon or strongly-burnt cryolite. Were the casting of aluminium to become an industrial operation, the metal would be more freely used in the finer branches of practical mechanics.

ANTIMONY.—Metallic antimony rarely occurs native and as an ingredient in the sulphides of other metals. Its chief commercial source is antimony sulphide (grey antimony), containing 74 per cent. antimony and 26 sulphur. The ready fusibility of this ore enables the usual dressing operations to be dispensed with; it is simply roasted in a furnace, generally of the kind shown in Fig. 6.

FIG. 6.



Here 2 chambers *f* are arranged between 3 fireplaces *a*, *b*, *c*, and covered with cast-iron lids perforated at spots corresponding with the centres of 2 fire-clay cylinders *e*, fitted above them in the arch, through which the fire reaches them, while the smoke escapes by flues at the back. Holes in the sides near the bottom of the cylinders correspond with openings into the arch, and are closed with fire-clay stoppers, and luted. Crucibles *d* are placed on low carriages in the chambers *f*, to receive the fused metal as it runs from the cylinders. When the furnace is heated to bright

redness, a charge of 4 cwt. of broken-down crude sulphide is put into the cylinders, which are then covered up; the metal fuses out and flows into the crucible beneath, leaving the gangue in the cylinder. The charge is renewed every 3 hours, and the residue is drawn out through the holes in the sides of the cylinder. The yield per hour is about 90 lb. of pure sulphide, which has various uses in medicine and pyrotechny.

To obtain the metal from this sulphide, the latter, in coarse powder, is roasted at a low heat in an ordinary reverberatory furnace. Much care is needed to regulate the furnace so that oxidation of the sulphur shall proceed uninterruptedly without risk of fusing the sulphide. The calcination should be complete in 12 to 15 hours, 100 lb. of the sulphide affording only 60 to 65 lb. of antimony oxide, though theoretically the yield would be 86 lb. This oxide (antimony glass) is used in the manufacture of enamels, and coloured pastes for artificial gems. To reduce the metal from the oxide, the latter is mixed with charcoal powder moistened with a solution of soda ash, and put into a number of crucibles in the same furnace, when a bright red heat is maintained till fusion is complete. The product is crude metal and scoria, the latter consisting of antimony and sodium sulphides in combination. The crude metal is re-melted with some of the scoria, which further purifies it; and again melted in large quantities with careful skimming, and slowly cooled.

The process adopted by the Costerfield Co., in Australia, for treating their ores, consisting of the sulphide and brown and white oxides of antimony (containing 33 to 65 per cent. antimony, and 15 dwt. to 4 oz. gold per ton), is as follows. The antimonial tailings from the stamp batteries are classified by buddling, and the rich antimonial portion thus separated from quartz detritus is collected in bags, dried in the boiler-house, put into a smelting furnace with equal portions of uncrushed ore, and reduced to crude antimony (sulphide); the resulting slag and cinder are further treated by roasting or calcining in a reverberatory furnace to liberate the oxide, which passes off in fumes from both furnaces into the oxide flue; this may be 1000 ft. long, and 4 to 6 ft. wide and high. As the fumes cool on their passage to the smoke-stack, the oxide is deposited in chambers constructed in the flue to receive it. The residue from the reverberatory furnace is afterwards crushed for the extraction of any gold it may contain. Another process based on fusing the antimony sulphide with a portion of metallic antimony, using the same metal with fresh charges of ore till it becomes rich in gold, and then separating the two metals by oxidation of the antimony, while suitable for ores rich in antimony, will not answer for those containing less than 30 per cent. of sulphide, as they are too silicious to fuse. Prof. Cosmo Newbery has introduced another method for treating such ores. They are placed uncrushed in a kiln, with sufficient salt to produce an amount of chlorine that will get rid of the sulphur, antimony, and arsenic. As soon as calcination commences, steam or watery vapour is introduced through the bottom of the kiln in such quantity as to keep the mass saturated, until all vapours of sulphur, antimony, and arsenic have disappeared. The charge is then drawn, and submitted to gold-extracting operations. The liberated metallic vapours are condensed by causing them to impinge against a series of discs. Antimony oxide collected in this manner is well suited for the manufacture of paint, if the temperature of the fumes has been lowered from that of the furnace till the vapour has been all condensed into solid particles of oxide in suspension. (See Lock's 'Gold,' pp. 1106–10.)

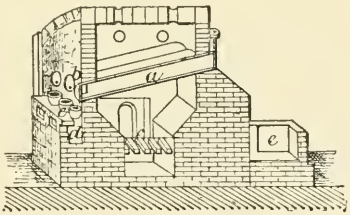
BARIUM.—The principal ores of barium are the sulphate or heavy spar ($BaSO_4$), and the carbonate or witherite ($BaCO_3$). Metallic barium may be prepared from the monoxide baryta, from the chloride, and from other salts, by electrolysis in presence of mercury; the

amalgam thus formed is heated in a tube containing petroleum, when the barium remains as a silver-white powder. Bunsen prefers to perform electrolysis on a pasty compound of barium chloride and very dilute hydrochloric acid, at a temperature of 212° F. (100° C.), in presence of mercury; the crystalline amalgam obtained, when heated, leaves the metallic barium as a porous tarnished mass, whose cavities sometimes appear silver-white. Matthiessen obtains better results by passing a galvanic current through barium chloride in a state of fusion, using as a negative pole a fine harpsichord wire, on which the metal deposits in little globules. Barium oxidizes very readily, and burns with brilliancy when heated in the air. Its melting-point is higher than that of iron.

BERYLLIUM or GLUCINUM.—This metal occurs in many minerals, especially the various forms of beryl, including the gems emerald and aquamarine. Wöhler first obtained it as a dark-grey powder by fusing the chloride with potassium. Debray's method of preparing it in the coherent form, by mingling the vapours of beryllium chloride and metallic sodium in an atmosphere of hydrogen, is as follows:—Into a glass tube is introduced first a boat of clay and lime containing metallic sodium, and then another charged with beryllium chloride; the air is completely displaced by dry hydrogen, when the boats and their contents are gently heated, with the result that the vapour of the beryllium chloride is carried over the sodium. The result is a strong reaction, by which the chloride is reduced to a metallic powder or mass of little globules; from this state it is rendered coherent by fusion under sodium chloride in a crucible. The metal possesses a sp. gr. of 2·1, and a bright silver-white colour; its melting-point is lower than that of silver. The compact form, heated before the blowpipe, takes on a thin film of oxide, which arrests further oxidation; the powdered form ignites when heated in the air, and burns brilliantly. Dilute hydrochloric acid dissolves the compact form readily; dilute sulphuric acid only when warm; but concentrated nitric acid only does so very slowly, even on heating: the dilute acids all dissolve the powder. Caustic potash dissolves both forms; ammonia, neither.

BISMUTH.—This metal occurs in many minerals, but not in such quantity as to make its extraction profitable. It is almost exclusively obtained from cobalt speiss at the Saxon smelt-works, the residue containing about 7 per cent. of it. The operation of smelting bismuth is extremely simple: the metal, having but weak affinity for other substances, is obtained by heating its ore in a liquation furnace in a cast-iron retort set on an incline, at the highest part of which the crude ore is charged; at the lowest angle is placed a cast-iron bowl, into which the metal flows. The furnace is illustrated in Fig. 7.

Fig. 7.



About ½ cwt. of broken ore, nearly as large as marbles, is charged into each retort *a*, of which there are usually 4 in a furnace side by side; this quantity nearly fills a retort, so that the upper part is empty. The lower end is closed with a clay slab *b*, provided with an aperture for the discharge of the melted metal. The pipes, when properly ignited, soon cause the metal to flow into the dishes *c*, which contain some charcoal-dust, and are heated by a separate fire *d*. By applying a brisk fire *f*, and stirring the ore, all the metal contained in it is obtained within ½ hour, the residue is scraped out of the retort into a trough *e* with water, and the pipes are filled afresh. About a ton of ore is melted in a day of

8 hours. The metal is re-melted, and cast into iron moulds in the form of ingots. The metal thus obtained may be purified by re-melting in a flat bone-ash dish, at a low heat, removing the dross as it appears on the surface. It is advisable to melt the metal thus reduced to a purer form, in a graphite pot, and then cast it into the mould for ingots. Bismuth cannot be freed from silver by these means, in consequence of which the commercial article always contains some of that metal.

The bismuth ores at Joachimsthal, Hungary, are smelted in crucibles with $\frac{1}{4}$ their weight of scrap-iron to combine with the sulphur, $\frac{1}{2}$ soda carbonate to convert the silica into a soda silicate slag, and $\frac{1}{21}$ each of lime and fluor-spar; 1 cwt. of the mixture is put into each crucible, part of the soda carbonate being used to cover the charge. The crucibles are closed by lids, and strongly heated till the contents become pasty, when they are well stirred, and, after complete fusion, ladled out into conical iron moulds, wherein the bismuth collects at the bottom.

Commercial bismuth is largely contaminated with arsenic, iron, and silver; these do not interfere with its general application in alloys, but much of the arsenic can be removed by heating under charcoal in crucibles, and the silver, when sufficiently abundant, can be recovered by cupellation at the cost of the bismuth being converted into oxide. Metallic bismuth is remarkable for its brittleness (somewhat less than antimony), low melting-point, great tendency to crystallize, property of expanding during solidification (increasing $\frac{1}{33}$), and diminishing in specific gravity under strong pressure.

CADMIUM.—This metal occurs in calamine and zinc blende in proportions varying from $1\frac{1}{2}$ to 3 per cent. It is recovered during the smelting of these ores for their metallic zinc in the following manner:—The more volatile cadmium vapour passes off with the first portions of the zinc distilled, imparting a brown hue to the flame; whence the term "brown blaze" is applied to this period of the roasting. The vapours burn in the air with formation of a mixture of cadmium and zinc oxides. The powder thus deposited is separately collected, mixed with charcoal in iron tubes, and distilled again, when the first deposit from this distillation will be found still richer in cadmium. The mixture is dissolved in dilute sulphuric acid, and the cadmium is thrown down as a sulphide by introducing sulphuretted hydrogen gas; the cadmium sulphide is washed, dissolved in strong hydrochloric acid, and converted into carbonate by adding ammonia carbonate; this cadmium carbonate is washed, dried, and distilled with charcoal to afford the pure metal. (Huntington.) Or, the mixture of cadmium and zinc is re-distilled, and the second product is dissolved in hydrochloric acid, from which the cadmium is precipitated by metallic zinc. (Roscoe and Schorlemmer.) Metallic cadmium possesses the colour and appearance of tin, which it resembles also in giving a crackling noise when bent; but it is harder and more tenacious. It can be cut with a knife, drawn into wire, and rolled into foil, but becomes brittle at 180° F. (82° C.). Its sp. gr. varies from 8·546 (cast) to 8·667 (hammered). It is capable of taking a high polish.

CÆSIUM.—This rare metal is met with in small quantities in the ores of other alkali metals (notably lithium), and in some mineral waters. On passing an electric current through melted cæsium chloride, little globules of the metal form at the negative pole, rise to the surface, and ignite; but the metal has not been obtained in a pure state. It stands first among metals in its electro-positive quality.

CALCIUM.—Calcium minerals occur throughout the world in the greatest profusion, the most familiar examples being the various forms of carbonate (chalk, coral, limestone, marble, and magnesium limestone or dolomite), and the sulphates (gypsum and anhydrite). Davy prepared metallic calcium as a powder by electrolysing calcium chloride in presence of mercury,

and heating the resultant amalgam. Matthiessen obtained it in a compact form by melting a mixture of 2 molecules calcium chloride and 1 of strontium chloride (with a little sal-ammoniac to facilitate the fusion) in a porcelain crucible, containing a carbon positive pole, and provided with a negative pole in the form of a thin harpsichord wire wound upon a stouter wire, and only just entering the liquid mixture. Beads of the reduced metal attach themselves to the fine wire. Liés Bodart reduces the metal by fusing a mixture of 1 part sodium with 7 of fused calcium iodide in a closed iron crucible, commencing with a dull-red and advancing to a bright-red heat. Caron fuses 3 parts fused powdered calcium chloride, 4 of fairly granulated distilled zinc, and 1 of sodium in small pieces, in a crucible heated to redness in an ordinary furnace. The action is feeble at first. When zinc flames begin to arise, the heat is moderated to check volatilization. After about 15 minutes in this state, the crucible may be withdrawn, and, on cooling, a metallic button will be found at the bottom. This alloy of calcium and zinc, containing 10 to 15 per cent. of the former, is placed in a gas-carbon crucible and heated till all the zinc is disengaged. Calcium has a sp. gr. of 1·5778; it is malleable, tenacious, harder than lead, and of a yellow colour; it oxidizes rapidly in moist air, but slowly in quite dry.

CERIUM.—This rare metal occurs in a few uncommon minerals, in the following approximate proportions, calculated as oxide (Ce_2O_3):—61 per cent. in cerite, 12½ in orthite, 8½ in wöhlerite, and 2¾ in gadolinite. It may be prepared in quantity in the compact form by electrolysis of the chloride. Its sp. gr. is 6·628 to 6·728; it has the hardness of calcspar, and can be hammered, rolled, and (warm) drawn into wire; its colour and lustre resemble those of iron, but, though fairly permanent in dry air, tarnish in moist air, passing through yellow and blue to green tints; its melting-point ranges between those of silver and antimony; it ignites more readily and burns with greater brilliancy than magnesium; it resists cold concentrated nitric and sulphuric acids, but dissolves in hydrochloric and in dilute sulphuric acid.

CHROMIUM.—This somewhat rare metal occurs chiefly in native lead chromate or crocoisite ($PbCrO_4$), and in chrome-iron ore or chromite ($FeO.Cr_2O_3$), the latter of which is mainly used for the preparation of chromium compounds. The metal is isolated by reducing the oxide or chloride. Deville intensely heats a mixture of sugar and chromic oxide in a lime crucible. Wöhler heats chromium sesquichloride with metallic zinc under a layer of sodium chloride, and treats the zinc regulus with nitric acid, when the chromium separates as a grey metallic powder. Bunsen obtains the metal in brittle glistening scales by electrolysis of a solution of chromous chloride containing chromic chloride. Fremy procures it in hard crystalline scales by heating chromic chloride in contact with sodium vapour in an atmosphere of hydrogen. Vincent finds that when chromium amalgam is heated in an atmosphere of petroleum, the metal remains behind in a pulverulent form. Finally, Zettnow has shown that when the metallic regulus formed by fusing the double chloride of chromium and potassium with zinc is treated with nitric acid, a residue of crystalline chromium is left. The sp. gr. of the metal forming a greenish crystalline powder is variously stated at 6·81 to 7·3. The metal is undissolved by hot concentrated nitric acid; slowly by cold dilute sulphuric, but rapidly on warming; and quickly in hydrochloric. Deville's fused metal is non-magnetic, as hard as corundum, and less easily melted than platinum; it oxidizes slowly when heated in the air or hydrogen, and burns brightly in the oxy-hydrogen flame. (See Alloys, p. 23.)

COBALT.—This metal occurs sparsely in some arsenical ores, usually accompanied by nickel; its chief sources are cobalt speiss ($[CoNiFe]As_2$), cobalt glance ($[CoFe][AsS]_2$), and cobalt

bloom ($[Co_3(AsO_4)_2 + 8H_2O]$). These ores are roasted or calcined in the air, yielding an impure cobalt arsenate, termed "zaffre." The iron is got rid of by a smelting process resembling that used in copper extraction; the roasted ore being fused with a flux of sand or lime carbonate, by which the iron slag rises to the surface, leaving the cobalt below as a heavy speiss. This latter is dissolved in strong hydrochloric acid, and any iron arsenate present is precipitated by careful addition of solution of lime chloride and a little milk of lime. The clear supernatant solution is drawn off and treated with sulphuretted hydrogen to throw down the copper and bismuth; cobalt oxide is then precipitated from the clarified solution by means of lime chloride, and is washed and ignited ready for the market. Metallic cobalt is obtained as a grey powder by igniting the oxide or chloride in a current of dry hydrogen, or the metal can be procured in a compact state by strongly heating the oxalate under a layer of powdered glass; and fused to a regulus by heating in a graphite, lime, or magnesia crucible. Cobalt melts at a lower temperature than iron, but is harder, malleable, very tough, and magnetic. It dissolves easily in nitric, hydrochloric, and dilute sulphuric acids; its colour resembles that of polished iron, and its sp. gr. is 8·5 to 8·7. In the coherent form, it suffers no change in the air at ordinary temperatures, but slowly oxidizes on heating, and at a very high temperature burns with a red flame.

COPPER. — *Properties.* — Copper is a light, hard metal, very liable to rust; all salts, unctuous bodies, and many other natural substances are solvents of it. It is remarkably sonorous, being the basis of all alloys in which that quality is sought for; and its divisibility is great. After hammering, its appearance is silky, and its lustre seems to be increased. Heated to fusion, it absorbs oxygen, oxidizes at the surface, and becomes covered with a black crust; and it may be converted into suboxide altogether by a strong heat in the muffle. At a high white heat it burns with a greenish coloured flame. In dry air, copper is unchangeable; in moist air, and in presence of carbonic acid, sulphuretted hydrogen, or other acids, it becomes dark, and assumes a bronze hue. It is a red-coloured metal, with a specific gravity of 8·78, which may be increased to 9·00 by hammering. The tenacity of cast copper is sufficient to support a weight of 19,000 lb. to the sq. in., or rather more than half as much as good cast iron. When heated, it rapidly loses strength, and at a dull-red heat is little more than half as strong as at ordinary temperatures. Pure copper in mass is hard, but capable of being cut with a knife. Its hardness is increased by hammering, rolling into sheet, or drawing into wire. If either of these processes be repeated sufficiently long, the metal is rendered extremely brittle; but its tenacity and malleability may be restored by a process of annealing. A fracture of the metal in a soft state is red, shining, granular, and, if very soft metal, it is crystalline. When hard, its fracture presents a fibrous, lightish-red, silky appearance. The increase of specific gravity from 8·78 to 9·0 by hammering was supposed to arise from the condensation of the particles of the mass; but when copper is melted in contact with the atmosphere, it absorbs oxygen, and becomes slightly porous. This absorption is prevented by fusion under common salt. The density of the metal so fused has been found to be 8·921; after being subjected to a pressure of 300,000 lb., it has been increased only to 8·930. The difference is so slight that it is probably owing to a diminution of the spaces still remaining, rather than to an approximation of the particles of the mass to each other. It has a disagreeable taste and smell. It is an excellent conductor of heat and electricity. Its power of conducting heat is 898, taking gold at 1000, iron being 374, and lead 179. A bar of copper heated from 32° to 212° F. (0° to 100° C.) is lengthened about $\frac{1}{580}$ part, while iron is extended only $\frac{1}{810}$. Copper in a finely-divided state, if pressed to-

gether and made red-hot, as in Wollaston's process of preparing platinum, may be welded together into a solid mass, provided it has been soaked in oil previous to ignition, in order to prevent oxidation. It expands in solidifying. The addition of 0·1 per cent. of potassium, zinc, or lead, will prevent expansion in cooling. It boils at an intense white heat, but is not volatilized. Exposed to intense heat in a close vessel, it incurs no sensible loss of weight. In a finely-divided state, on ignited charcoal, it burns like tinder; if, on being lighted, it be put into an atmosphere of oxygen, the combustion becomes very vivid, the metal being converted into protoxide. Lengthened exposure of the bright metal to a humid atmosphere causes its oxidation, and it becomes covered with a green carbonate of copper, commonly, but incorrectly, termed verdigris. Heated to redness in contact with the air, it oxidizes, and the scales of oxide fall off. With care, at a low-red heat, bars of it may be worked by the smith in the same manner as iron. It is soluble in acids, but mostly so in the oxygenating acids.

Cleaning ore.—Copper occurs chiefly in 3 forms:—native, as sulphide (copper pyrites), and as carbonates. The 2 latter forms undergo a series of operations for the extraction of the metal. These often commence by a rough process of classification in the mine; but frequently the whole of the stuff broken off the lode is sent up for dressing. At the surface, cleaning is commenced by separating the large from the small stuff, for "spalling." This operation, which is commonly done by men, consists in breakng the large stones into pieces of 2 or 3 lb. weight. The resulting broken mineral is divided into 3 parcels, viz., "best ore," "poor ore," and "attle," or worthless matter, which is discharged from the dressing-floors. The "best ore" of this operation, with the smaller fragments of the pile, are "cobbled" by young females—a repetition of the spalling process—reducing the pieces still smaller; they are again sorted into 3 parcels; but the best ore is conveyed direct to the crushing-mill, or placed aside for that purpose. The poor ore of the spallers is subjected to the cobbling process, and is similarly divided. If careful dressing is pursued, the poor ores of the several cobblers are again sorted into the 3 divisions. The ores of the miner, other than the smallest, are thus reduced to 2 qualities, and a considerable portion of the matrix is rejected in this early stage. The treatment of the 2 qualities of ore is essentially different.

Crushing.—Formerly the best was invariably crushed under flat hand-hammers, or cobbling-hammers, on iron plates or old stampheads, by females; and in mines producing but little ore, this method is still pursued. The cast hammer has a square face, and weighs about 4 lb.; with this primitive instrument, the ore is crushed so as to pass through sieves of 4 to 64 meshes or holes to the sq. in. If the ore is of more than average richness, it is broken to pass through the fewer meshes; if poor, to pass through the larger number. Crushing is now almost universally effected by roller-mills or stamp-batteries, as described at length in André's "Mining Machinery." The best ore is passed through a coarse riddle, and taken from the mill to the pile for sale. Poor ore is passed through a riddle with small meshes, and from the crushing-mill is taken to the dressing-floors, where it undergoes a succession of operations in order to partially free it from extraneous matter, thereby increasing the average percentage of metallic copper before offering it for sale.

Jigging.—The first of these operations is technically known as "jigging" the ore in a cistern of water. Formerly this was universally done by filling a quantity of ore into a copper-bottomed sieve, and then taking it by the handles, plunging it into the cistern, giving it a jerking, and at the same time a semi-rotatory motion. The act of forcing it quickly into the water causes a momentary suspension of the lighter pieces; after a few repetitions of the process, these are found ranged at the

top, while the largest fragments of ore sink to the bottom of the sieve, nearly in the order of their specific gravities. A thin stratum is now scraped off the top and thrown aside, a fresh quantity of ore is added to that already in the sieve, and the process is repeated. This is continued until the contents of the sieve consist almost exclusively of ore of average richness, when it is delivered to "pile." In the bottom of the cistern there will have been collected the fine particles of ore which passed through the meshes of the sieve: the water is drained off, and this is also carried to "pile." The very finest ore held in suspension by the water is collected and cleaned. The hand process of jigging is applicable only to small quantities of ore; when large quantities are to be washed, machinery driven by steam or water power is substituted for the hand-sieve, and the manual labour is confined to filling and skimming. Machine-wrought jiggers work on the same principle as the hand apparatus. The wooden cisterns are larger, being 6 ft. long, 4 ft. wide and deep, arranged endwise along a narrow shed. At each end is a wooden framework 6 ft. high, supporting a wooden frame lever, the short forked end of which projects over the cistern, and is connected by iron suspension straps to a square sieve. To the other and longer end, the common proportions of which range from 18 in. to 11 ft., an iron rod is attached in connection with a small crank on the body of a longitudinal shaft, which is driven at a quick speed. A second lever, with a rod reaching to the attendant, serves to lift the sieve through the slotted suspension straps whenever a cessation of the motion is required. The sieves measure 4 ft. by 2 ft. wide, and 9 in. deep, strengthened by iron bands and numerous laths across the bottom to support the wire-work. Iron sieves are rarely admissible, owing to the destructive action of the mineralized water; and brass lasts a shorter period than might be imagined. The size of the mesh is regulated by the mesh of the revolving riddle of the crushing-mill; if the latter is 4 to the lineal in., the sieve will contain 5 or 6. Many novel forms of jigging machines will be found described and illustrated in André's "Mining Machinery."

Buddling.—The ore carried away by the water is partly collected by passing the current to a circular buddle. At first it passes into a wooden cistern, in which revolves a short cylindrical block, having on its periphery a number of stout projecting spokes. In its revolutions, the spiked cylinder agitates the liquid, which escapes by a short trough into a second cistern, containing a similar revolving block, armed with a number of projecting paddles. This apparatus still further agitates the passing mixture. From the second cistern it flows by a short trough into the upper end of a cylindrical riddle, revolving in an inclined direction, and discharging at the lower end any pebbly matter. The fine particles fall into the cistern under the riddle, and are conveyed by the current to the centre of the buddle. This consists, in general terms, of an excavation 18 to 24 ft. diameter, and 2 or 3 ft. deep, with a floor rising 8 or 9 in. to the centre, where is fixed a conical wooden block. A vertical spindle carrying a funnel-shaped hopper, with two projecting arms, rests on the central block, and is driven by bevel gearing at the top. To each of the projecting arms is attached, by cords running over pulleys, a board, fitted on the lower face through its length with a brush. The weight of the board is balanced to an extent by small blocks attached to the suspending cords. On one side of the excavation is a small sluice-gate through which the water is permitted to escape as the excavation fills with matter. The ore and water enter through the funnel, and striking against the apex of the conical block, are distributed radially over the bottom. Motion being communicated to the central spindle, the hanging boards and brushes are drawn lightly over the surface of the accumulating ore. By attention to the balancing weights attached to the cords, the

force with which the brushes press on the mass, during their passage, may be regulated to the requirements of the ore. The value of the deposit in the excavation is determined in the same manner as with the simplest kind of buddle ; namely, the richest portions at the head or centre, near the entrance of the liquid, gradually diminishing in value to the edge of the pit, where a broad ring of "tailings," or worthless matter, is taken out. The central portion is carefully taken out as clean ore, while the portion between this and the tailings is subjected to a repetition of the agitating and buddling process.

The water from the buddle holds in suspension a quantity of fine ore, which separates, to a great extent, by allowing the water to remain for a period in large pits ; it is then drained off, and the sediment deposited on the bottom is removed to undergo a cleansing process. This may consist of a revolving "trunking" apparatus. A revolving spindle carries two broad paddles ; these work in a small cistern, into which the fine ore is placed, and a stream of water enters. In front of a small cistern is a longer cistern, of the same width, but slightly declining to the outlet. With each revolution of the paddles, a small quantity of the mixture passes into the long cistern, and flowing slowly over the smooth surface, the solid matter suspended in the water is again deposited, but this time in bands of varying richness, the heaviest and most valuable particles being at the upper end. A portion of the remainder is placed aside for re-operating on ; but the extreme portion is not of much value if the operation has been carefully conducted.

Mention must be made of the ore rejected as too small by spallers and cobbers ; it is picked over, and the richest pieces are passed to the best-ore heap. The remainder is subjected to a riddle with 1-in. meshes, and again through one with $\frac{1}{2}$-in. meshes. The large from both these processes is picked over, and, along with the small, subjected to dressing operations similar to those already described.

The further treatment of the ores for the extraction of the copper is conducted in 2 distinct ways, known respectively as "dry" and "wet" methods.

Dry methods.—The processes herein involved may be classed into 2 principal groups, the English and the German. Taken on the whole, these groups have a common feature in that they both consist of a succession of roastings and fusions which gradually eliminate the sulphur and other foreign matters. But they possess distinct characteristics. The English method adopts a reverberatory furnace, proceeds rapidly, but entails complex manipulations requiring skilled labour ; it terminates in an operation wherein the reduction of the products to a metallic state is effected by a double decomposition of oxygenated and sulphuretted combinations. The method is appropriate to the nature of the materials generally treated, rich ores of various composition. The German method, on the contrary, is slower, and consists of roastings and fusions carried on in different apparatus. The roasting is generally done in heaps, or better in stalls ; the fusion in low blast furnaces. This latter method is considered preferable for poor and impure ores, and is more economic for districts where fuel is scarce and dear.

Summarized, the German method, taking for example that practised in the Hartz for impure sulphides, comprises the following operations :—

1. Roasting the ore in heaps of 50 to 100 tons.

2. Smelting for crude matte with a mixture of ore cinders from the subsequent smelting, and fluxes. The matte obtained holds 25 to 35 per cent. copper.

3. Roasting the crude matte (generally 3 fires).

4. Concentrating smelting of roasted crude matte, raising the copper to 45 or 50 per cent.

5. Roasting the concentrated matte, which is performed more thoroughly than the previous one, up to 5 or 6 fires.

6. Smelting for black copper, giving

a thin matte of 65 per cent. copper, a little impure black copper, and cinders holding 1½ per cent. copper.

7. Roasting the thin matte at 7 or 8 fires.

8. Renewed smelting for black copper and thin matte.

9, 10. Fresh roasting and fresh smelting.

11, 12. First fining of black copper, and fining at low heat.

As to the two operations of roasting and smelting, they offer no particular difficulty of execution. In the roasting, it suffices to mix the ore and fuel (mineral or vegetable) in successive layers, whose arrangement carefully preserves access of air. The amount of fuel and number of successive operations are determined by the degree to which the roasting is to be carried. For the smelting, the materials, properly proportioned and well mixed, are charged in at the top of the furnace, in alternate layers with the fuel; draught is effected by a blast at the bottom; a tap-hole situated near the base allows of the outflow of molten metal.

The English method comprises:—

1. Roasting the ore in a reverberatory furnace.

2. Smelting for crude matte, in the reverberatory.

3. Roasting the crude matte, also in reverberatory.

4. Smelting for rich matte, also in a reverberatory.

5. Calcining the matte, which is repeated several times to produce more complete purification.

6. Fining and refining.—All these operations are carried on in a reverberatory furnace, whose form and dimensions are suited to the particular end in view.

Successful economical management of smelting operations is dependent principally on due assortment of the ores for the various operations involved in their preparation, and for the final production of metallic copper. These operations are 10 in number; and for them the crude ores are assorted into 5 classes, viz.:—

1. Such ores as contain 3 to 15 per cent. of copper combined with sulphur, and with iron also mineralized with sulphur, forming iron pyrites and arsenic associated with quartz and other siliceous and earthy minerals.

2. Ores of similar constitution, but containing 15 to 25 per cent. of copper.

3. Sulphides of copper, with less of the sulphides of iron, containing 15 to 20 per cent. of copper, a portion of which is in the state of oxide, principally associated with siliceous minerals.

4. Principally oxides and carbonates of copper with some of the sulphides, containing 20 to 30 per cent. of pure metal, the associated minerals being principally siliceous.

5. Rich oxides of copper, free from sulphur and arsenic, or other metals which can have an injurious effect on the metal, obtainable from these ores, which contain 60 to 80 per cent. of copper, the accompanying minerals being chiefly quartzose.

The 10 operations involved in the treatment of these ores are as follow:—

1. Roasting ores of the first and second class, for the separation of such of the constituents as are capable of being volatilized by the action of heat—sulphur, arsenic, zinc, antimony.

2. Fusion of the calcined product of the first operation with minerals of the second class not previously calcined. This operation is termed melting for coarse metal.

3. Roasting of coarse metal.

4. Melting for white metal. In this operation the coarse metal is fused together with ores of the fourth class.

5. Melting for blue metal. The calcined coarse metal is fused with roasted ores rather rich in copper.

6. Remelting of slags from operations 4, 7, and 8.

7. Roasting of white metal for the production of white metal of superior quality.

8. Roasting for regulus.

9. Preparation of crude copper by roasting and fusion of regulus.

10. Refining and toughening of crude copper, producing fine metal.

For the purpose of showing clearly

the character and objects of these 10 operations, considered in detail, the following statement of analysis of the constitution of the more common ores is necessary:—

Copper	Antimony	Sulphur
Iron	Zinc	Alumina
Arsenic	Lead	Silica

The separation of the copper in a state of purity is, of course, the object of all the operations just enumerated. As a simple chemical question, it can be comparatively easily done on the scale of ordinary laboratory operations; but for practical purposes, the same means cannot be adopted, principally on account of the too great cost of the agents required, but also because of the too great nicety of process for the ordinary labour employed in such extensive operations.

The First Operation has for its object the separation of all the substances capable of being volatilized by heat. This is effected by exposing the ore, in a roughly pulverized condition, to the joint action of heat and atmosphere in a reverberatory furnace shown in plan and

Fig. 8.

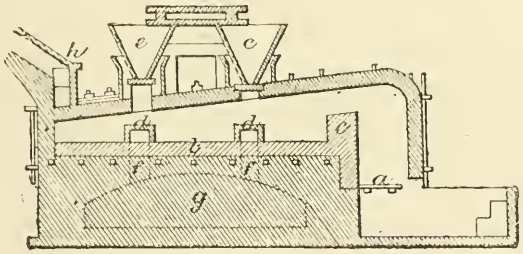
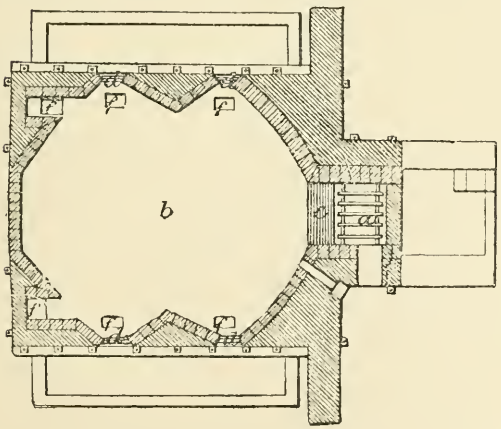


Fig. 9.



section in Figs. 8 and 9. The furnace consists of a fireplace *a*, for the production of the heat, and of a sole *b*, on which the crude ore is subjected to its action. They are divided from each other by the bridge *c*, which is so con-

structed as to admit heated air to the gases produced in the fireplace, which, for the regular distribution of the heat over the whole of the sole of the furnace, requires to be ignited, not within the fireplace, but at the back of the bridge, so entering into full combustion, and producing streams of flame over the whole surface of the sole. As the production of an oxidizing flame should be the object in this furnace, the proper arrangement of the bridge for controlling the admission of air is of the greatest importance. The regular distribution of the heat over the whole of the furnace is effected by having the arch 3 ft. high over the bridge, gradually diminishing to 1 ft. over the back bridge. The sole of the furnace is usually 16 to 24 ft. square, having 2 doors *d* on each side, through which the workman rakes over (rabbles) the charge of ore at intervals of 1½ to 2 hours, so as to expose fresh surfaces to the action of the heated air passing over it. The charge is introduced through hoppers *e* fixed in the arch of the furnace; and when the calcination is completed, it is drawn through holes *f* in the bed or sole of the furnace into an arched recess *g* below. The bed of the furnace may with advantage be extended to 60 ft. by 16 ft., being divided into 4 different parts, each 3 in. higher than the other. The consumption of coals in this operation need be but very small, as when the ore is first introduced, the assistance of heated air alone is sufficient to maintain the combustion of the sulphur of the ore, the heat from which causes the evolution of arsenious acid from the arsenic. The gradual increase of heat in the charge is very necessary to be provided for, as with too much heat the charge, while still holding much sulphur and arsenic in combination, is very liable to be fused; and in this condition the evolution of the sulphur and arsenic is very much impeded, as is also the oxidation of the other metals present. When the charge is drawn, it still contains some sulphides and sulphates; most of the sulphur, arsenic, antimony, and zinc, will have been evolved; the copper and iron, not remaining in combination with sulphur, will have been converted into oxides; and the siliceous or earthy matters will remain unchanged. Unless a very large quantity of arsenic and other volatile metals shall have been driven off, the charge, when drawn, will not differ much in weight from the charge put into the furnace, as the sulphur evolved will have been to a considerable extent replaced by the oxygen of the air, which will have combined with the other metals, producing oxides. The volatile products pass off into the flues, where a portion is deposited; but the remainder, consisting principally of sulphurous and sulphuric acids, together with the carbonic acid, water, and nitrogen, the products of the combustion of the fuel, are diffused from the top of the chimney *h* through the surrounding atmosphere. By the adoption of means hereafter noticed, a very large proportion of this sulphur is rendered available, in the form of sulphuric acid, for the numerous manufacturing purposes for which this important chemical agent is required; and thus, while a valuable product is obtained, the deleterious effects on the surrounding country are confined to a much more limited extent.

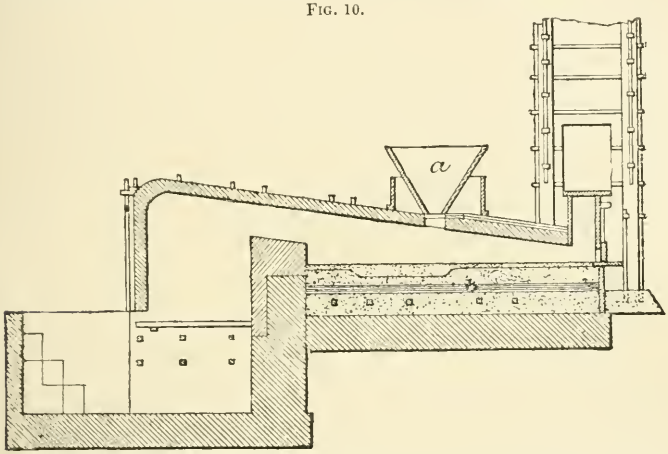
The reverberatory furnace may be built of copper slag-blocks, cast in moulds 18 in. by 9 in., faced internally with fire-brick, and externally with fire-brick or common brick; the whole laid with fire-clay; the fronts and sides covered with plates of cast iron, bound together with cast-iron studs and wrought-iron braces. The products of combustion pass off over the back bridge into a descending flue, or into underground flues, communicating with the main shaft or chimney.

A still further economy of fuel may be effected by constructing the back beds of the furnace of cast-iron plates, causing the heated air and gases to circulate in flues below the plate before finally passing away through the descending flue. The cast-iron soles are more durable than the fire-brick usually employed; and the labour for rabbling or turning over the charges may be applied with

much greater effect. Lengthened experience has shown that the cast-iron plates are not affected by the united action of heat and sulphur, as might have been anticipated.

Second Operation.—The reverberatory furnace employed in this operation is about $\frac{1}{3}$ the capacity of that employed for calcining the raw ore, supposing it to be a single furnace. Its construction is shown in Fig. 10. It is built also of the same materials; but as a

Fig. 10.



very much greater heat is produced within it, much more care is necessary in its construction. It is charged through the hopper *a* with about 20 cwt. of material, consisting of calcined ore from the first operation, a small proportion of crude ore, a small quantity of fluor-spar as a flux, some of the scoria of the same operation, and fusible scoria from the fourth, fifth, and seventh operations. The ore and flux having been introduced through the hopper, the workman rapidly spreads the charge over the bed *b* of the furnace, and then introduces the scoria, evenly distributing it over the surface of the ore. The furnace door is carefully closed, and for $3\frac{1}{2}$ hours the fire is steadily raised, the charge being left undisturbed. Within $\frac{1}{2}$ hour after the closing of the furnace, the fusion of the scoria commences: it flows down, and carries the heat rapidly through the charge, which immediately begins to give off sulphurous and other gases, causing an ebullition of the liquid scoria; a rapid reaction is produced between the earthy and metallic constituents, the iron and silica entering into combination, and, with the assistance of lime of the fluor-spar, forming with the alumina present a very liquid scoria, through which the heavier fused copper sulphide falls to the bottom, where, from the peculiar hollow form of the bed, it is all brought together. At the end of $3\frac{1}{2}$ hours, the furnace door is opened, the furnace-man clears off with his rake the unfused portions remaining around the sides of the furnace, turning them into the liquid mass, which acts rapidly on them, reducing them also to the liquid condition. The door is again closed, and the fire is urged on to greater intensity. At the end of another $\frac{1}{4}$ hour, the furnace is carefully tapped at the bottom of the basin, so as to allow the liquid mass to run off into an iron cylinder immersed in water. In this manner the mass is granulated, and brought into a suitable form for the

next operation. While the liquid mass is still running off, the furnace door is opened, and the liquid scoria is raked off into moulds, formed by digging oblong cavities in sand; or it is sometimes cast, if sufficiently clear of copper, in cast-iron moulds, forming blocks suitable for a variety of building purposes. As soon as the charge is drawn, the furnace is re-charged, and the work is continued as before; so that in 24 hours, 6 charges are passed through the furnace. Ores containing fluor-spar are more valuable than those which contain silica alone; not only do they not require so much silica to be removed, but they also provide a flux for other ores which are siliceous. It is evident, therefore, that much judgment is requisite for the due assortment of the ores for this process. The object of this operation is to separate the metallic from the earthy matters; the products consist of about $\frac{1}{3}$ coarse metal, composed principally of copper and iron sulphides in nearly equal quantities, and $\frac{2}{3}$ scoria, containing iron, silica, alumina, lime, and calcium fluoride (fluor-spar), all fused together into one homogeneous substance. The cast blocks of scoria are carefully examined when cold, to determine whether any coarse metal be left in. The peculiar colour and form of fracture of the brick give a very nice indication of the quantity of copper, down to so minute a proportion as $\frac{1}{1000}$ to $\frac{2}{1000}$ part. The portions containing matte or coarse metal, usually amounting to about 7 per cent., are separated, and reserved for a new charge for the same operation; the remainder is carried off to the waste heap.

The fluor-spar employed as a flux is peculiarly valuable, both as a mechanical and as a chemical agent. Under the influence of heat, it fuses on coming into contact with silica, the calcium obtaining oxygen; the silicon and fluorine set free from the calcium combine, and, as a gaseous product, in passing off, produce an agitation of the fluid mass, which is highly conducive to the perfect reaction of the various constituents on each other. The lime thus set free immediately enters into combination with another portion of silica, forming with the other earthy matters present, through the assistance of a portion of the iron, a very fluid slag; the cylinder containing the granulated matte is lifted out of the water by a crane fixed to the furnace, and is removed in wheelbarrows or waggons to the furnace employed for the next operation.

Third Operation.—For this, precisely the same sort of furnace is used as for the first operation. It is charged in the same manner, from the hoppers on the roof of the furnace, with the product of the second operation, which may be regarded as copper pyrites free from gangue or earthy matrix, and containing about 33 per cent. copper. The heat employed in this operation is much greater than in the first, as the constituents of the charge are not nearly so fusible. The object is to drive off as much as possible of the remaining sulphur. The fire requires to be managed so as to produce an oxidizing flame, that is, flame greatly supercharged with atmospheric air, undecomposed, but highly heated by the fuel. This necessity arises from the fact that heat alone is not sufficient for the expulsion of the sulphur; but when heated oxygen is brought into contact with the materials of the charge, it partly combines with the sulphur, forming sulphurous acid, the detachment of the sulphur from the iron and the copper being facilitated by the intervention of other quantities of oxygen entering into combination with the metallic bases, forming oxides, principally of copper and iron. The alternate employment of an oxidizing or clear flame, and of a reducing or smoky flame, is advantageous, as, under the influence of the former, sulphates are sometimes formed. The residuary sulphides, with the sulphates, are more rapidly decomposed by their reaction on each other, under the influence of the reducing flame, than they would otherwise have been, the sulphur of the sulphide combining with a portion of the oxygen of the sulphuric acid of the sulphate, its base obtaining its oxygen from the same source, the sulphurous acid passing off.

The charge begins to throw off vapours as soon as it gets red-hot throughout, or in about 2 hours after it is put into the furnace. It is then well raked over, to cause every portion in succession to be exposed to the action of the heated air passing through the furnace. The raking or rabbling is repeated every 2 hours, the heat being maintained as high as possible, short of causing the charge to fuse. At the end of 24 hours, the heat will be equal to about cherry-red; and at the end of 36 hours, at a bright red, by which time the calcination should be complete, and the charge ready to draw. The product of this operation is "coarse metal," which should be as nearly as possible pure oxides of iron and copper. It is much altered in colour, and reduced to a coarse granular condition much smaller than before. If well done, the fragments are of a deep black colour, with some indications of incipient fusion on the grains. Much more coals are consumed in this than in the first operation, but not so much as in the second.

Fourth Operation.—The furnace is of the same form as that employed in the second operation, excepting that there is no basin-formed recess in the bed, but a gradual slope of it, so as to discharge the whole of the fused mass readily from a hole in one of the long sides. The charge is composed of coarse metal, the product of the third operation, mixed with minerals of the fourth class, such as copper sulphide free from admixture of iron pyrites, or the carbonate or oxide of copper and copper slag from the ninth and tenth operations; together with copper scales from the rolling of copper or other copper wastes, such as are produced in the working of copper into utensils for machinery. The object of this operation is to separate the iron by combining it with silica, forming a silicate of iron, leaving the copper in combination with sulphur in such proportion as will form a sulphide of copper. With such a variety of materials to work on, a superior class of workmen is required for conducting this operation; for they are not limited by such rigid rules as in the previous operations, being allowed to operate on successive charges, as may be indicated by the results of previous workings. The materials for a charge amount to about 30 cwt. The charge is introduced through the side door, and is spread over the bed with an iron slicer, shaped somewhat like an oar or paddle. The door is carefully closed, and the heat raised as rapidly as possible. During the first 2 hours a calcination goes on, attended with the evolution of some sulphurous acid, and an incipient fusion takes place as the heat increases. The charge flows down, until, at the end of the third hour, the fusion is complete, the scoria is very liquid, and remains quiet in the furnace. Between the fourth and fifth hours, the charge is well and rapidly stirred; the unfused portions of the charge adhering to the sides are turned into the liquid mass; and then the furnace is again closed, and the heat is urged until the whole of the interior of the furnace is raised to a dazzling whiteness. At the end of 6 hours the furnace is tapped, the matte is run into water, and thereby granulated, the very liquid scoria being conducted through another channel, after the matte has been run off into sand moulds. The scoria is sorted into 2 qualities; the first run off, having been in contact with the matte, retains 3 to 5 per cent. of copper, and is reserved for the sixth operation; the last portion run off contains much less copper, and is used as a flux in the second operation. The matte, consisting principally of copper sulphide, still retains 4 to 8 per cent. of iron sulphide, and contains 70 to 75 per cent. copper. This matte is termed "white metal." In its purest form it is of a greyish-white colour, of a granulated porous texture, sometimes of a bluish-grey colour, with a specific gravity of 5·2 to 5·7. It is reserved for the ninth operation. The working somewhat resembles the second operation; but as the heat required is much greater, more fuel is consumed; 22 charges are worked through the furnace in a week.

Fifth Operation.—The furnace employed precisely resembles that used for

the fourth operation; and, indeed, the 2 operations much resemble each other. The charge on the present occasion consists of materials containing fewer metallic oxides than those of the last, but having more metallic sulphides. Excepting that some of the products of the present are brought into other operations, together with the products of previous processes, it would hardly require a separate description, but would rather be an equivalent for the fourth operation; its principal object being, by the better selection of ores containing a less variety of substances, to produce from them a "blue metal," from which blue copper may with less difficulty be elaborated. The white metal, the product of the fourth operation, does not contain any metallic copper; but the blue metal is characterized by the presence of metallic copper, diffused throughout the mass in exceedingly minute particles.

About the same quantity of fuel is used as in the fourth operation, the reactions that take place in the furnace are similar, and the products are disposed of in much the same manner. The matte contains 70 to 75 per cent. copper.

Sixth Operation.—The object of this operation is, by the combined action of the various constituents of the slags from the sixth, seventh, and eighth operations on each other, to cause the production of a matte in which the copper in these slags shall be brought together. A small quantity of copper pyrites, free from other combinations than siliceous matter in large proportions, is mixed with the slags. After the mass is fused, a little coal or other carbonaceous matter is mixed with the charge, which reacts on the oxide of copper, decomposing it, and producing a metallic copper, which alloys with any tin, nickel, cobalt, or arsenic present, and, falling to the bottom under the matte, does great service by eliminating these metals from the superincumbent matte. The same sort of furnace is used as in the last operation; but the materials of the charge, instead of being supplied to the furnace through a hopper in the roof, are introduced through the ordinary working door and another door placed more nearly in the corner of the furnace; the fused charge is drawn off from the side opposite to the working door. Each charge of 2 tons takes about 6 hours for working off. The products are: white metal for the sixth operation; red metal, for the same operation; the bottoms, or alloy of metals, divided into tin alloy and copper alloy, for the ninth operation; scoria, for returning to the fourth operation; and slag, to be rejected to the extent of 90 per cent.; so that it will be seen that this operation is very efficient in the reduction of bulk of useless materials.

The Seventh Operation is carried on in a furnace resembling the one used in the sixth. The charge consists of about 2 tons of blue metal only, without any other flux than the sand adhering to its surface from the moulds in which it was cast. As the operation is twofold—first for calcination or oxidation, and then for fusion—the bridge is provided with an air-passage, similar to that employed in the calcining furnace for the first operation. The charge is put into the furnace in large masses, and the heat is slowly raised upon it, so as to oxidize as completely as possible the metal present. When the whole mass is fused, the iron sulphide having been converted into iron oxide and sulphurous acid, the silica reacts on the iron, and is converted into a fusible silicate; some copper oxide is also scorified, but the matte or white metal produced is much improved in quality, and rendered fit for the eighth operation. The operation requires about 12 hours for its completion; and but little alteration has taken place between the weights of the charge introduced and of the products obtained, none of the latter being finished with, but having to be redistributed to the furnaces for the second, fourth, and sixth operations.

The Eighth Operation is conducted in a furnace precisely similar in every respect to that employed for the seventh. The materials constituting the charge

are white metal, produced from the sixth and seventh operations, together with the red metal from the sixth, without any other flux than the sand adhering to the blocks from the moulds in which they were cast. The operation lasts about 4 hours, the weight of the charge being about 1½ ton. At first, as in the last operation, the effect is that of oxidation; but as the fusion proceeds, the copper oxide which has been produced, coming into contact with copper sulphide, a reaction takes place, sulphurous acid is evolved, and metallic copper is precipitated, or a copper subsulphide is produced. The products are 3, all of which have to be re-worked. They are—1st, a regulus, consisting of 81 copper, ·2 iron, nearly 2 per cent. sulphur; 2nd, a slag, consisting almost entirely of silica, and iron and copper oxides, with about 10 per cent. of copper mechanically mixed; 3rd, copper bottoms, or alloys of copper with other metals. These are reserved for the ninth operation; and some of the slag is returned to the furnace for the fourth operation.

Ninth Operation.—The same sort of furnace is used as in the last. The charge, amounting to 2½ to 3¾ tons, consists of white metal from the fourth operation, regulus from the eighth operation, copper bottoms from the sixth and eighth, and a small proportion of rich oxide or carbonate ores, associated with quartzose matrix or gangue. No other flux is added than the silica of the rich ore. The heat of the furnace is at first regulated for the calcining of the charge, and is gradually raised until the whole mass is perfectly fused. The object of the calcination is to promote the oxidation of the metals and of the sulphur: the sulphur, being converted into sulphurous acid, passes off, together with arsenic if it be present. By fusion of the oxidized matters, copper oxide is brought into contact with copper sulphide, oxygen leaving the copper and combining with the sulphur; the 2 in combination, assuming the gaseous form, produce a most desirable agitation of the constituents of the charge, whereby in succession matters having chemical reactions on each other are brought into contact, and the desired changes are effected. As only a limited supply of oxygen is contained within the charge, and this is soon exhausted by the reactions that take place within the fluid mass, it becomes necessary to obtain a fresh supply. In the fused state, the charge presents but a very small amount of surface for the reaction of the heated air passing through the furnace. The production of the necessary surface for the further oxidation is effected in a simple but ingenious manner. The furnace is allowed to cool, by opening the doors, down to a dull-red heat; in so doing, the crust formed over the surface of the fluid mass is broken up by the sulphurous acid passing off. As the charge throughout becomes more and more pasty, it is rendered more porous by the gas evolved, through the agency of the oxygen of the heated air coming into contact with it, which at the same time that it is expelling the sulphur, is also being stored up within the mass by the combining action of the copper, iron, and other metals present. At the end of about 12 hours, the charge is so far cooled that the disengagement of gas ceases. The doors are again closed, the heat is gradually raised during the next 6 hours, fusion slowly takes place, calcination at first going on; and after the mass has again become fluid, the mutual reactions of the oxides and sulphides, as before indicated, again take place. The heat is then urged on to the utmost; the silica and iron, entering into combination, produce a slag, together with the remaining small proportions of antimony, arsenic, &c., through which the fused metallic copper finds its way to the sole of the furnace.

At the end of 24 hours the charge is drawn, the slag being skimmed off, and the metal cast into blocks about 3 ft. long and 18 in. wide. This product is known as "blistered" copper, and amounts to about 60 per cent. of the weight of the charge put into the furnace. The residuary slag, which not unfrequently contains 15 to 20 per cent.

of copper, is sorted and returned to the furnaces for the fourth and sixth operations. The blistered copper is so called because the surface of the ingots is covered with blisters; the interior is full of cavities, the fractured surface, when fresh, being of a deep-red colour.

Tenth Operation.—Refining the coarse metal produced in the last process is conducted in a similar furnace, having a larger fire-place and the roof somewhat higher above the sole, so as to allow of the piling of the charge of ingots, 7 to 10 tons weight, on and over each other. These require to be so arranged as to allow of a free draught through the furnace, but with a regular equable distribution of heat. During the first 18 hours, the workman has only to maintain the fire so as steadily to raise the heat of the furnace.

Calcination and oxidation at first go on during the slow fusion, as in the last operation, more sulphur being evolved; and when the fusion is complete, the silica adhering to the ingots fuses, together with some of the copper oxide, at the same time laying hold of most, if not all, of the other metallic oxides remaining in combination. At the end of 22 hours, the scoria thus produced is raked off, leaving the surface of the metal as clean as possible. A few shovelfuls of powdered wood-charcoal, or finely-pulverized anthracite of the best quality, are thrown on the surface of the charge, and rapidly spread over it. A short time after this, a pole of green wood is plunged into the fused metal; a violent ebullition takes place, causing a more intimate mixture of the copper and the charcoal; and probably the steam and gaseous products evolved assist in the elimination of any traces of sulphur left within the metal. This action with the pole, termed "poling," is maintained for about 20 minutes. The superintendent then takes out a small sample of the metal in a ladle; when cooled, he examines it by cutting the ingot half-way through with a steel chisel, then bending it in a vice back to a double, by which means the fibre of the metal is developed, the colour and flexibility are ascertained, and it is determined whether the refining is complete.

If the poling has not been continued long enough, the metal will be brittle, as also if the poling has been continued too long. In the latter case, the metal is restored, but with some difficulty, by clearing the surface of the metal, and allowing heated air to pass over it, apparently for the purpose of decarbonizing the metal. When the metal has been overpoled, it becomes exceedingly bright and brilliantly clear, so that the roof of the furnace may be seen reflected on its surface. Before poling, the copper is in a peculiar condition, termed the "dry state," probably consisting of much copper oxide and oxygen in contact with the metal. In this condition it has a very strong action on the iron tools used in working the charge. The desired point having been attained by the refiner, the charge is again skimmed, a smoky flame is produced in the furnace to prevent oxidation, and the metal is taken out in ladles covered with a wash of fire-clay, and cast into moulds, varying according to the quality or form required for the market. Various qualities of copper are met with in the market; they are known as "best selected," "tough copper," and "tile copper." These vary in quality, according to the choice of products for the tenth or refining operation.

Scorification.—When the copper is to be rolled into sheet, about $\frac{1}{2}$ part of lead per 100 of copper is added just before skimming the surface, the whole being then well stirred, so that the action of the air may produce a lead oxide, which combines with the oxides of the foreign metals present to form a slag, which can be skimmed off before casting. The oxidation of the added lead must be complete, as even $\frac{1}{10}$ per cent. will injure the quality of the copper.

The various modifications of this process, introduced of late years in England, are mainly designed with one common object—the utilization of the sulphur for making sulphuric acid. Economy of fuel is another consideration.

As modified, the series may be stated thus:—

1. Roasting in special furnaces (Spence's and Gerstenhöfer's), which allow of the collection of this sulphurous acid in leaden chambers for conversion into sulphuric acid.

2. Smelting the roasted ore in a blast furnace.

3. Roasting the matte in heaps or in a reverberatory furnace.

4. Fusion for black copper in a blast furnace.

5. Fining and refining in a reverberatory furnace.

In brief, the reverberatory furnace is reserved for operations needing an easy access of air simultaneously with a pretty intense heat; and the blast furnace is preferred for fusion, as in it the contact with the fuel permits a more complete utilization of the heat generated. (For details of Spence's, Gerstenhöfer's, and other improved furnaces, as well as the manufacture of sulphuric acid, the reader may refer to Lock's 'Sulphuric Acid,' and the art. Acid, Sulphuric, in Spons' 'Encyclopædia.'

Wet methods.—The wet treatment can be employed alone or in conjunction with a certain number of the operations of the dry system. In any case, it is adapted only to those poor ores whose gangues are not attacked by the acids used. The solution of the copper is effected by different methods. Operations may commence by sulphatizing by means of a suitably conducted roasting, then dissolving out in water the sulphates formed. Or the ore may be attacked directly by acids, either previously prepared or produced in contact with the ore. The acid treatment is applied to naturally oxidized ores or sulphides oxidized by roasting. Whatever the means adopted for the solution of the copper, the latter is precipitated by scrap-iron, affording the product known as "copper cement." The wet method is widely used. At Agordo, it is worked successfully on sulphides containing only 1½ per cent. copper. The process as there carried on deserves some further notice.

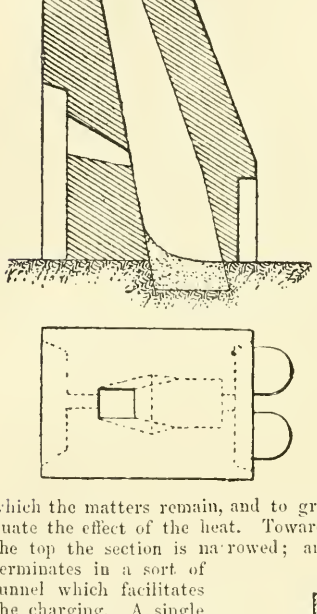
Agordo plan. — The characteristic phase of this process is the roasting of the poor ores; this operation is conducted with extreme slowness, and is arrested while there still remains a notable proportion of sulphur in the cores of the lumps. Owing to the gradual nature of the roasting, part of the sulphur is sulphatized, and part driven off in a state of vapour; the latter is condensed and collected, affording an article of commerce. But at the same time (and this is the important point), there is produced in the interior, even, of the lump of ore, a molecular movement of the copper towards the centre, when the sulphur is in excess; thus is created pieces whose external crust is sensibly impoverished, while the core is much richer in copper than the original ore. This earthy poor crust is removed by hand-breaking and sifting, and treated in the wet way; while the lumps are added to naturally rich ores for smelting in a blast furnace.

The process of the wet method applied to the poor portion comprises a series of very methodical successive lixiviations, terminating by a fresh roasting, and a final washing before rejecting the matters as waste. There is a production of waters charged with iron and copper sulphates, which are decanted and concentrated, and the copper is precipitated by iron or cast-iron; thus is obtained a pulverulent matter, which is dried, and passed on to the smelting for black copper. This material contains, according to Petitgand: 55 per cent. of copper containing 55 to 60 per cent. pure metal, 12 per cent. of 10-per cent. metal, and 33 per cent. of pure copper. As to the mother liquors, they are concentrated by natural evaporation in well-ventilated rooms, and afford crystallized iron salts.

The metallurgical treatment proper comprises crude smelting of the ore, roasting the matte afforded, smelting for black copper, fining, and refining. The first smelting is generally effected in such a furnace as that illustrated in Fig. 11. The characteristic feature is the inclination of the breast and of the

back from rear to front, the object of which is to increase the period during

FIG. 11.

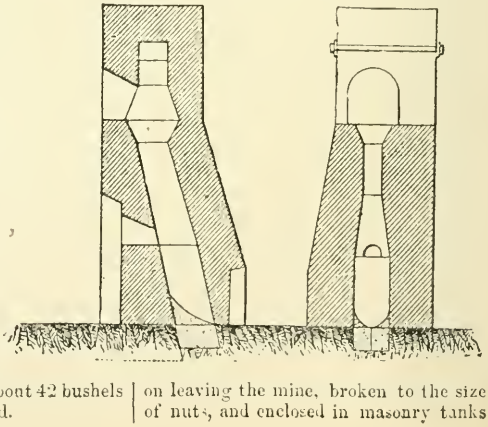


which the matters remain, and to graduate the effect of the heat. Towards the top the section is narrowed; and terminates in a sort of funnel which facilitates the charging. A single tube, supplying air under a pressure of 1 centim. of mercury, suffices to support the combustion in each furnace, while a flue conducts the gases from several furnaces to a common chimney. This operation treats 15 or 16 tons of material per 24 hours; the materials consist of rich pyrites, enriched lumps, deposits of "cement," cinders, and ashes of previous operations; the fuel employed is wood charcoal, the consumption of which is about 42 bushels per ton of copper produced.

The crude matte is roasted 5 times in stalls containing 8 to 10 tons; each firing lasts 2 hours, and consumes about 14 bushels of charcoal and ½ ton of wood. The smelting for black copper offers no special peculiarity; the type of furnace used is shown in Fig. 12: it is equally characterised by the inclination from rear to front. The draught is also effected by a single tube introducing air under 6 centim. of mercury; the output is about 9 tons per 24 hours, with a consumption of 33 to 36 bushels of wood charcoal per ton of copper produced. The fining and refining are effected by the German method. Two fires arranged together are ordinarily employed for this work, receiving about 8 cwt. per charge, and consuming 42 bushels of charcoal per ton of metal obtained. In fine, the Agordo method is a combination of the dry and wet systems, especially characterised by the mode of enriching adopted at the first roasting.

Carbonated ores.—The treatment of carbonated ores with a quartzose gangue is often done by means of acids, either hydrochloric or sulphuric. Sometimes the latter is produced actually in contact with the ore. The wet method is reserved for ores holding less than 3 per cent. copper; these are carefully sorted

FIG. 12.



on leaving the mine, broken to the size of nuts, and enclosed in masonry tanks

about 160 ft. square and 4 ft. 6 in. deep. A sort of grating made of wooden bars is placed at a depth of 16 in.; it receives in the order of their size the lumps to be attacked, finishing with the finest matters, the total charge being about 25 tons. A mixture of steam and sulphuric vapour is introduced into the lower portion of the mass, condenses in traversing it, and constitutes the solvent liquor of the copper. The acid vapours are obtained by roasting, in a furnace 15 ft. high, pyrites mixed with $\frac{1}{1000}$ part of nitre and $\frac{1}{300}$ part of sodium chloride; special boilers, having a heating surface of about 24 sq. ft. per ton of matters roasted, furnish the necessary steam. Every 4 days the upper part of the heap of ore is turned by shovels; the total duration of the solvent action is 25 to 30 days. The solution finished, the liquor is drawn off, the ore is washed, and the copper is precipitated by scrap-iron, a part of the "cement" reaching a yield of 80 per cent. of copper after drying. The black copper is smelted in a reverberatory furnace and then fined; the rest, which is less rich and very pulverulent, is passed into a blast furnace, as at Agordo.

This method has long been improved upon, for very poor ores, by the use of special solvents, consisting of the mother-liquors arising from the manufacture of iron sulphate, of hydrochloric acid, and of cementation liquors containing sulphate and acetate of protoxide of iron. The iron acetate in particular causes a rapid decomposition of the copper carbonates. The first step is to thoroughly aërate the liquors which have already served for a previous precipitation, in order to oxidize them; next to methodically wash the ore, taking care, after each washing, to repeat the aëration by a current of compressed air. The liquors in passing successively over less and less exhausted ore arrived at a suitable degree of concentration; the copper is precipitated, the mother-liquors are concentrated to separate a good part of the iron sulphate, and restored in the routine of the works. In this way can be treated 10 times as much ore as formerly, or about 150 tons daily, besides utilizing much poorer mineral.

Commercial forms.—Copper is brought into the market in a variety of forms, such as bean-shot or feathered shot, intended for the manufacture of brass. The former of these is produced by pouring the melted copper through ladles filled with holes, into hot water, for the production of bean-shot, or cold water for the manufacture of feathered shot. It is cast into slabs when required for hammering out into shape for large utensils, such as vacuum pans, in which case a small slab, with the aid of a steam-hammer, is hammered out into the form of a hemisphere, with a rim 8 to 9 ft. in diameter out to out, and 4 ft. deep. It is also cast into ingots of various sizes. One form of ingot is only 6 oz. in weight, and about 8 in. long. It is exported to the East Indies as Chinese or Japan copper. These ingots are of a fine red colour, produced by casting them on canvas stretched under warm water. The method of producing this colour was for a long time kept secret. The slabs are also, some portion of them, before being sent away from the smelting works, converted into sheets of varying thickness, by rolling between smooth iron rollers, each about 3 ft. 8 in. long, and 15 in. in diameter. The ingots of copper to be operated upon are heated in a reverberatory furnace, and are then passed through the rollers, returning over them, and passed through again and again, until by cooling and hardening they become so brittle that they require to be annealed by reheating in the furnace. The rollers are gradually brought closer together by tightening screws bearing on the plummer-blocks carrying the shaft of one of the rollers. The repeated re-heatings of the sheet produce a coating of oxide, which is removed by steeping for a few days in urine; it is then put again into the furnace, the ammonia attached to the surface is driven off, and the sheet being plunged while hot into cold water, the cupric oxide formed scales off, leaving the metallic surface bare. After passing the sheet, when cold, through the rollers,

to produce a smooth surface, it is cut down to the proper size and packed for the market.

Hardening and Toughening.—Everitt of Birmingham uses 1 to 6 per cent. manganese oxide (the best is the natural black oxide) and mixes this with the copper in a crucible. As soon as the mass is melted, the oxide is thoroughly stirred in, and the resulting scum carefully removed: it is then fit to cast. In the preparation of brass, the same takes place, and then the zinc is added. Although chiefly used for brass-plating, it is well adapted for other platings in which copper forms a chief ingredient. The copper is rendered more homogeneous, harder, and tougher; it can be rolled at a red heat, thus saving a great deal of time and labour. It has shown itself best suited for steam-pipes, axle-boxes, ship-plates, &c. (*Iron Age.*)

Trials made at the Mansfield Copper Works have proved that an addition of 0·45 per cent. of manganese-copper is sufficient to toughen copper, which only retains 0·005 to 0·022 per cent., while the greater portion, after having taken away the absorbed oxygen, is carried off in the refinery slag. Manganese-copper has also a beneficial influence upon the toughness and density of thin copper castings, such as thin sheets, tubes, kettles, cauldrons, and other kitchen utensils, which formerly were beaten or pressed into shape; copper cast with an addition of the alloy shows itself extremely tenacious, and tubes of $1\frac{1}{2}$ in. diameter and only 0·07 in. thickness will stand a pressure of over 1100 lb. per sq. in., when water begins to be pressed through the pores of the metal. It appears that "cast copper," which can be brought in any required shape without the necessity of soldering, beating, hammering, pressing, or drawing, will in future play a considerable part in the arts and manufactures.

Some samples of black copper oxide and pig copper from Colorado were sent to Egleston to examine for arsenic and antimony, but he found none present. A quantity of this material was purchased by a large metallurgical works, and when they attempted to refine it, they pronounced it to be full of arsenic and antimony; so much so, that their furnaces were, as they said, "poisoned," and rendered unfit for refining. He then re-examined the samples, and at the same time some of the material which had "poisoned" the furnaces, and found no traces of arsenic or antimony when the usual amounts for analysis were used; but on taking very large amounts, he found traces merely in some parts of the sample, but not in all. As it was a matter of interest to ascertain what the white substance that "poisoned" the furnace was, he sent to the works making the black copper, and obtained some of the matte from which the black copper was made. He then found the impurity to be tellurium, a substance not heretofore known as occurring in copper. He gives the following analyses of the matte, and of the black and refined copper:—

	Matte.	Black Copper.		Refined Copper.
Copper . .	55·02	97·120	98·690	99·705
Gold . . .	0·66	..	..	..
Silver . .	0·40	0·132	0·128	0·135
Lead . . .	17·87	0·777	0·757	none.
Zinc and Nickel .	2·22	0·070	0·100	0·024
Iron . . .	4·18	0·130	0·080	0·031
Sulphur . .	20·62	0·236	..	trace.
Tellurium .	0·12	0·093	0·097	0·083
Arsenic . .	..	0·006	..	0·091
Slag, &c. .	..	1·270	0·192	..
	99·89	99·834	99·444	100·069

The mattos and the black copper are results of the treatment of copper ores with the tellurium ores of Colorado. In the laboratory no traces of white fumes were shown on charcoal; but when the metal in the furnace was subjected to the process of "dry roasting," as was unintentionally done, very dense white fumes were given off. When refined and cast into cake, it had the ordinary appearance of cake copper. At the first pass in the rolls, very fine cracks showed themselves, and the copper was rendered "red short." (*Trans. Amer. Inst. Min. Engs.*)

The common impurities found in commercial copper are—antimony, arsenic, bismuth, iron, lead, nickel, silver, sulphur, and tin. Antimony and sulphur reduce its malleability and tenacity. Arsenic in small proportion does not seem to have much effect, but when added to the extent of 1 in 10, it produces a white malleable alloy, much harder than copper, and not easily tarnished; this alloy is made by heating 5 parts copper shreds with 2 of white arsenic in alternate layers under a coating of sodium chloride in a covered earthenware crucible, and is used for dials and scale-rods. Bismuth and nickel decrease the toughness of copper; lead, even $\frac{1}{10}$ per cent., destroys its good qualities; phosphorus ($\frac{1}{2}$ per cent.) hardens it, augments its tenacity, and tends to preserve it in sea-water; while a little tin increases its toughness. All impurities seriously impair the electrical conductivity of copper. According to some tables relating to pure copper wire for electrical purposes, issued by W. T. Glover & Co., of Manchester, pure copper weighs 555 lb. per cub. ft.; the resistance of 1 mil. foot at 60° F. ($15\frac{1}{2}$° C.) is 10·32311 ohms; the resistance varies with the temperature at about 0·21 per cent. per 1° F., or 0·38 per 1° C.; a stranded conductor of a given length has a greater weight and a less resistance than an equal length of the same number of wires unstranded; No. 0000 BWG wire is 0·454 in. diameter, 0·161883 sq. in. in area, weighs 0·623924 lb. per ft., measures 1·60276 ft. per lb., and has a resistance of 0·000050084 ohm per ft., or 19966·5 ft. per ohm, or 12457·5 lb. per ohm, or 0·0000802 72 ohm per lb.; while the corresponding figures for 30 BWG wire are 0·012 in. diameter, 0·000113097 sq. in. area, 0·0004359 lb. per ft., 2294·13 ft. per lb., 0·07168825 ohm resistance per ft., or 13·9493 ft. per ohm, or 0·0060804 lb. per ohm, or 164·462 ohms per lb.

Tubes.—Tubes are either rolled by machinery and the edges brazed together, or they are drawn in such a way as to be seamless. From $\frac{3}{4}$ in. to 5 in. external diameter are the usual limits of size for brazed tubes, and beyond these sizes they are made by coppersmiths, and not by tube-makers. Solid-drawn copper tubes are made up to 9 in. diameter; solid-drawn brass tubes are made of all sizes between $\frac{1}{2}$ in. and 4 in. external diameter. The quality of brass tubes depends not only on the manufacture, but on the alloy of the brass. Tubes are usually made in lengths of 14 ft. to 16 ft., and are sold by lineal measure.

For bending copper tubes, the almost universal practice is to fill the tubes with lead or rosin, then bend them round a chuck or something of the same radius as that required for the bend. The lead or rosin may then be melted out. A machinist at Philadelphia, some years ago, devised an ingenious apparatus for this purpose, which, however, has not come into general use. It consists of a flexible mandrel of steel, made of wire of square cross-section, and with the coils lying in contact so as to form a close spiral. By inserting one of these of the right diameter into the tube, it can be bent to any angle without showing the slightest symptom of wrinkling; when properly bent, the mandrel can be readily withdrawn by simply taking hold of one end of it and drawing on it, giving it at the same time a slight twist to lessen its diameter. At the time this invention was first brought out it was said to answer its purpose very well.

Welding.—The great obstacle heretofore experienced in welding copper has been that the oxide formed is not fusible. If any fusible compound of this oxide could be found, it would render such a weld possible. We find in mineralogy two copper salts of phosphoric acid, viz.—libethenite and pseudomalachite—each of which melts readily before the blowpipe. It was therefore natural to suppose that a salt which contained free phosphoric acid, or which would yield the same at a red heat, would make the weld easy by removing the oxide as a fusible slag. The first trial was made with microcosmic salt

(soda and ammonia phosphates), and succeeded perfectly. As this salt was dear, it was found advisable to use a mixture of 1 part soda phosphate and 2 boracic acid, which answered the same purpose as the original compound, with the exception that the slag formed was not quite so fusible as before. This welding powder should be strewn on the surface of the copper at a red heat; the pieces should then be heated up to a full cherry-red or yellow heat, and brought immediately under the hammer, when they may be as readily welded as iron itself. For instance, it is possible to weld together a small rod of copper which has been broken; the ends should be levelled, laid on one another, seized by a pair of tongs, and placed together with the latter in the fire and heated; the welding powder should then be strewn on the ends, which, after a further heating, may be welded so soundly as to bend and stretch as if they had never been broken. Rust states that, as long ago as 1854, he welded strips of copper-plate together, and drew them into a rod; he also made a chain, the links of which had been formed of pretty thick wire and welded.

It is necessary to carefully observe two things in the course of the operation: (1) The greatest care must be taken that no charcoal or other solid carbon comes into contact with the points to be welded, as otherwise copper phosphide would be formed, which would cover the surface of the copper, and effectually prevent a weld. In this case, it is only by careful treatment in an oxidizing fire, and plentiful application of the welding powder, that the copper can again be welded. It is, therefore, advisable to heat the copper in flame, as, for instance, a gas flame. (2) As copper is a much softer metal than iron, it is much softer at the required heat than the latter at its welding heat, and the parts welded cannot offer any great resistance to the blows of the hammer. They must, therefore, be so shaped as to be enabled to resist such blows as well as may be, and it is also well to use a wooden hammer, which does not exercise so great a force on account of its lightness. (*Eng. Mech.*)

Alloys.—See pp. 11–21, 29–31, 34–5, 40–2.

DIDYMIUM.—This rare metal occurs in small proportions in a few uncommon minerals, notably in gadolinite, which contains about 8½ per cent. of the oxide, and in cerite (less than 4 per cent.) It is extremely difficult to isolate it from the other rare metals with which it is associated. Marignac prepared it in the metallic state by heating the chloride with potassium, obtaining it in the form of a powder or very small globules; while Hillebrand and Norton procure it in larger quantities by electrolysing the fused chloride. It most resembles lanthanum, but has a darker colour its sp. gr. is 6·544. On exposure to the air, it tarnishes yellow, and filings of it burn with great brilliancy when held in a flame.

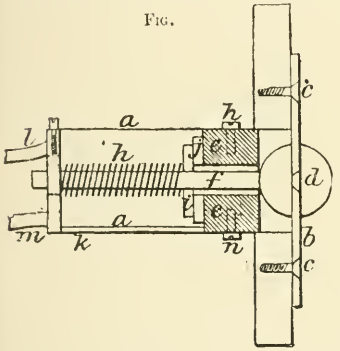
ELECTRICS.—This article is designed to convey a number of practical hints connected with the various branches of applied electricity, such as cannot be found in any existing treatise. Attention will be confined to strictly useful matter, the subject being divided into convenient heads.

Alarms.—Electrical apparatus is eminently adapted for alarms, tell-tales, and time signals.

House Electric Alarm.—In Fig. 13, *a* is a small piece of brass tubing, having a brass disc *b*, soldered on to one end of it. This is drilled and countersunk for screws, as at *c*; *d* is a small brass knob, either screwed or soldered on to the brass rod *f*, and protruding about half-way through a hole in the disc *b*; *e* is a circular disc of ebony fitting into the tube *d*, and having a hole through its centre to allow *f* to slide freely. The ebony is held in its place by screws. To one end of the ebony disc is fitted a brass circle *j*, of rather smaller diameter than *e*, also having a central hole to admit of *f* sliding. *h* is a spiral spring, which keeps the brass cross piece *i* (passing through a hole on *f*) in contact with the brass circle *j*. *k* is a brass disc closing the end of the tube, and also allowing *f*

o slide. One wire *l* is attached to this; he other wire *m* passes through a hole in *k*, and is attached to the brass circle *j*. On pressure being applied to *d*, the points of contact are forced apart, and no current can pass. Immediately, however, on the pressure being removed (as by opening a door or window), the spring recovers itself, and brings the cross-piece into connection with *g*, thus

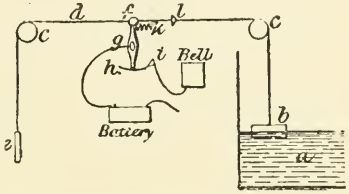
FIG.



closing the contact. These contact-makers are sunk in the lintel of the door or in the groove of the window, as shown in the figure. One of these must be used for each door or window to be guarded. The wires *l* and *m* should be guttapercha-covered, as, in fact, all wires used in this job should be. The rest of your work is comparatively easy. You must have an indicator in your bedroom to show which room is attacked. This will be precisely similar to those used in ordinary electric-bell work. At some point in the battery wire which goes to the indicator, you may insert an interrupter, which is merely a brass arm pivoted at one end and resting on a brass stud at the other. When you desire to throw the arrangement out of gear, you have only to remove the arm from the stud.

Tell-tales for Cisterns.—(1) In Fig. 14, *a* is the tank, *b* the float, *c* V-wheels, *d* light wire rope, *e* counterbalancing weight (which must be adjusted so as not to prevent the float *b* falling with the water), *f* eye (through which the wire rope passes), fixed on arm, which, being pivoted at *g*, is kept against the stop *h* by spiral spring *k* until the stop *l*, fixed on the wire rope, is brought in contact with *f* by the rising water, when the weight *e* pulls the arm over to *i*, which brings the bell into circuit. By moving the stop *l*, the bell can be

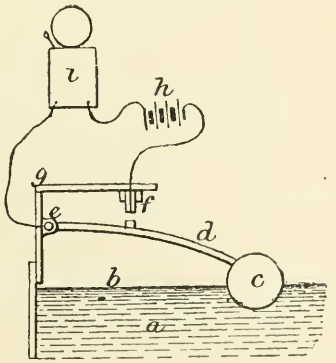
FIG. 14.



caused to ring at any level of the water, and by having another contact at *h*, and bell, and also a stop on the other side of *f*, the bell will ring when the tank is empty. When 2 bells are fitted up, the arm must be arranged to remain between the contacts, when not acted upon by the stops on the wire rope. An indicator and scale attached to the weight *e* will show the height of water in the tank.

(2) In Fig. 15, *a* is the tank, the height of the water being at *b*; *c* is a tin float

FIG. 15.

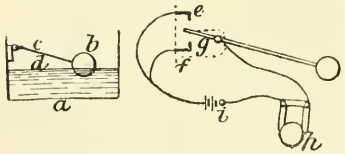


attached to the end of an iron rod *d*, moving on a hinge at *e*. *f* is a metal

stud tipped with platinum. A small piece of platinum is also soldered on to the point on the rod *d*, opposite to *f*. *g* is a wooden support to which *e* and *f* are fastened. A wire from *f* is carried to the battery *h*, which consists of a few Leclanché cells. The other terminal of the battery goes to one of the binding-screws of the electric bell *i*; the other binding-screw is connected by a wire to *e*, but care should be taken to have this wire in good *metallic* connection with the rod *d*. When the water rises to a certain height, the points at *f* will be put in contact, which completes the electric circuit and sets the bell ringing. The bell would cost about 4*s*. or 5*s*.; the batteries about 3*s*. each.

(3) In Fig. 16, *a* is the cistern; *b*, a float; *c*, the contact maker; *d*, a projection to hold float. The right half of the figure shows the contact-maker. *e* is a brass stud in contact with the line wire and *f* is another stud also

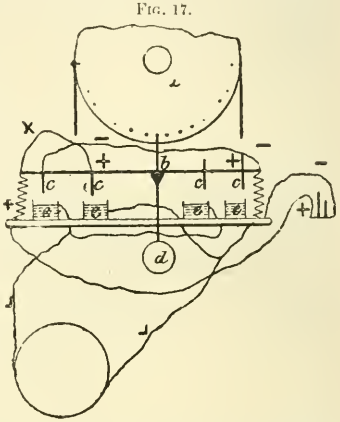
FIG. 16.



connected with the same wire. *g* is a piece of brass spring with the other wire attached to it; *h* is an electric bell, and *i* the battery. Platinize all contact points. The action is as follows:—When the cistern is full, the brass spring *g* touches *f*, and the bell rings. When the cistern is empty, the spring *g* touches *c*, and thus completes the circuit. It will be found very useful to employ a switch, so that when the cistern is full, the circuit can be broken, and thus save your battery. The same can be done when it is empty.

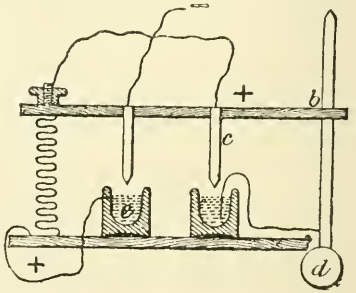
(4) In Figs. 17, 18, 19, the wheel *a* is actuated by the float, and when revolving, causes the bar carrying the contact-pins to rock on its centre *b*, thus producing a circuit on one side or the other by immersing the pins *c* in the mercury *e*, the pendulum *d* bringing the bar into its normal position. The pins are shown in a line for the sake of clearness, but they can be placed anyhow, so long as they dip together. By using mercury, you will make a great deal better contact than you can with solid

FIG. 17.



metals, but the pins on the bar and the connections must be well insulated. For the recording instrument you will require a couple of ratchet wheels of equal size, but fastened together a little

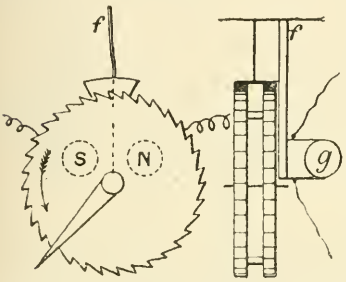
FIG. 18.



apart, and mounted on a common centre. You must have as many teeth on them as your float-wheel has pins, and the teeth must be cut in an opposite direction to one another, so that when the electro-magnet *g* attracts the armature

and escapement *f* toward the pole marked *S*, the wheel at the back revolves in the direction of the arrow (and with it the wheel and index that are shown); the reverse action takes place when armature, &c., is drawn towards N.

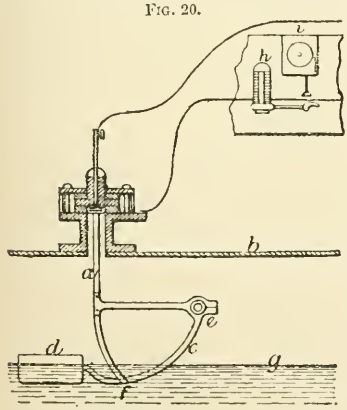
FIG. 19.



There are several disadvantages in this plan—viz., the necessity of having the batteries at the reservoir, the liability of the instrument to get out of step, and the continuous action if the pins on float-wheel should happen to hold the bar down.

(5) Field & Thompson combine a low-water alarm with an anti-incrustator for steam boilers, as shown in Fig. 20.

FIG. 20.



The current of electricity is caused to pass from the shell of the boiler to a negative electrode situated in the water so long as the level of the water does not fall below a predetermined point; when this level no longer obtains, the current, or a part of it, operates a signal. A dynamo, or other electric generator is provided, and a conductor in connection with the negative pole (that is, the pole which comes from the zinc plate in an ordinary voltaic cell) is passed through the shell or body of the boiler, in such a way that it is electrically insulated. This conductor, which terminates in, or acts as, an electrode, is so arranged that it is normally in connection with the water in the boiler, and by means of friction, part of it is kept clean and bright, so that it may make good electrical connection with the water.

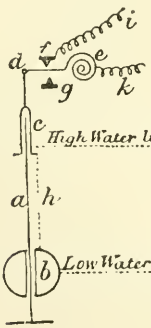
To convey the electric current to the water, and keep the conducting surface or electrode bright, there is fixed to the insulated negative conductor *a*, at or near the level of the low-water line in the boiler *b*, a metallic surface, against which *c* is made to rub, the motion of the latter being derived from some contrivance such as a float *d* actuated by the motion of the water. The float and rubbing surfaces *c* are insulated (at the joint *e*) from the boiler *b*, and from the negative conductor *a*, when not in contact with the submerged clean surfaces *f*. The float and rubbing surfaces are so arranged that when the level of the water *g* in the boiler falls below the predetermined point, the rubbing piece *c* shall not be in contact with the cleaned surface *f*. Thus all electrical connection between the rubbing surfaces of *f*, and the negative conductor or electrode *a*, will be broken, and the electric current through the boiler (whose shell forms part of the circuit) will be stopped. The circuit through the water being broken, the low-water alarm or indicator is brought into operation. A convenient method of indicating this is to cause the current to pass through the coils of an electro-magnet *h*, which attracts its armature so long as the current flows. When the circuit is broken, the armature will fall, and the current will be

"switched" into the signalling apparatus *i*, which may be of any suitable construction, such as a trembling bell, or an electric lamp, or an electric motor that will open a steam or water-cock and extinguish the fire.

The drawing shows a trembling bell in conjunction with a plate on the back of the armature, which plate bears the word "stopped," and assumes an attitude in which it is plainly visible when the armature falls, as it does when the current through the boiler ceases. The electric generator may be used in conjunction with a second battery. In cases where the prime mover does not run during the night, a secondary battery is particularly serviceable, as it keeps up the action during the time when there is little or no circulation in the boiler.

(6) Fig. 21 shows an arrangement for signalling both high and low water levels: *a*, upright guide-rod firmly

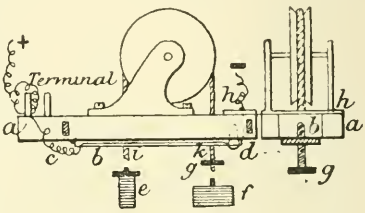
FIG. 21.



fixed to bottom of tank; *b*, hollow copper ball, with tube through it to slide over *a*; *c*, cap or tube with flange to slide over *a* at lower end, and attached at top end to *d*, lever arm mounted on spiral spring *e*, the centre of which is fixed to a rigid square pin; *f g*, 2 ends of a brass plate, projecting from a support at right angles to *d*; *h*, a light chain, connecting *c* and *b*, the length of which regulates the water-levels at which the bell will ring; *i k*, terminal wires, attached respectively to *f* and *e*. At low-water level the weight of *b* will bring *c* into contact with *g*; at high level, its buoyancy will bring *c* into contact with *f*.

(7) In Fig. 22, *a* is a wooden frame; *b*, contact-lever; *c*, hinge to contact-

FIG. 22.

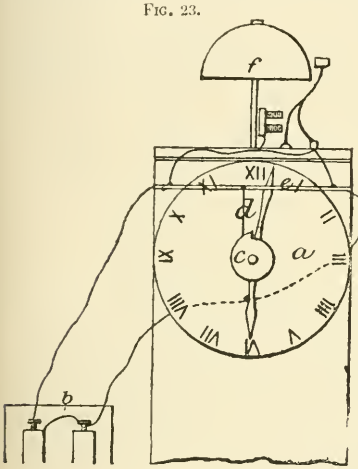


lever; *d*, brass contact-screw; *e*, counter-weight and stop to prevent weight from passing through lever; *f*, float; *g*, stop for same; *h*, piece of tin for *d* to contact on; carry wire to contact screw, as shown in sketch, along the lever. When the water gets below a certain point, it would leave the float suspended, which should by the counter-weight *c* lift the contact-lever at *i*, and make contact at *d h*. On the contrary, the float *f* should lift lever at *k*, and again make contact at *b h*. To ensure success, the float should be as heavy as possible, the lever as light, and the counter-weight heavy enough to lift the lever. The holes in contact-lever should be large enough to clear rope or chain. Pulley should not be less than 5 or 6 in. in diameter.

Time-signals. — (1) To ring at 6 o'clock. Fig. 23 shows a small clock *a*, with which to work the bell; *b*, battery consisting of two Leclanché cells; *c*, a disc, with a notch cut in it, running out to the diameter of the disc, and having a groove in it in which *d*, a small piece of wire runs; attached to *d* is a small strip of sheet copper *e*, and fixed to it is the gong *f*. Set the small point in *c* to the hour required for the alarm to ring, and it will be seen that, when the recess in *c* works round opposite the hour, the wire *d* drops down in the recess, bringing with it *e*, which falls on the two ends of the wire from the

battery brought in at the sides of the clock. The strip *e* cannot be seen, being above the face. The disc could be fitted to any clock, being nothing more than a piece of sheet brass with a groove cut in it with a file, to prevent the wire from slipping out. There should be a

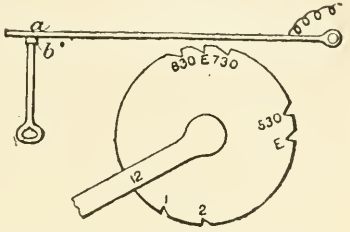
FIG. 23.



switch, to turn the current off or stop it. The gong is shown as fixed on the top of clock, and battery and clock on mantel-shelf. A common house-bell will do for a gong, supported on a piece of brass wire. The disc *c* is of course to be carried by the hour hand.

(2) Have a disc, about 2 in. diam., fastened on to the shaft of the hour-hand, so that it revolves once in 12 hours, and notched about ⅛ in. deep, to allow the pin of contact-rod to drop, and make contact at *a b*. Divide the disc into 12 equal parts for the hours, and half the spaces for the half-hours, and number them as shown in Fig. 24, when fixed, the centre of the hour-hand should always be over the figure 12. Carry the wire from the battery to the contact-rod, as shown, and not through the joint. This will ring the bell all through the night; but you can switch it off and on, or, if this is unsuitable, make the disc revolve only once in 24 hours, and divide and notch to suit, so that more than one half of disc would

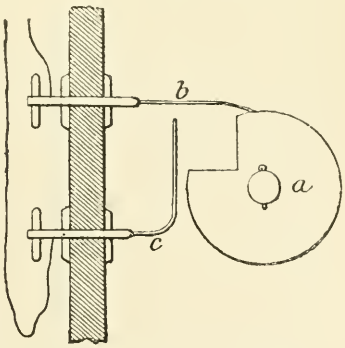
FIG. 24.



be blank. The contact-rod you must shape to circumstances, and make the minute and hour hands coincide.

(3) In Fig. 25, *a* is a disc of thin sheet brass, with notch cut in it;

FIG. 25.

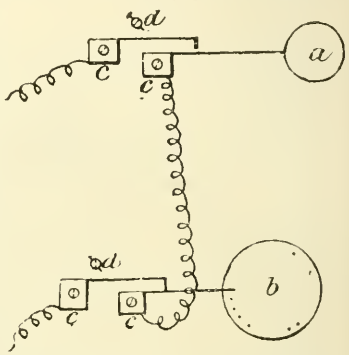


through the centre is soldered a tin tube to slip tightly on the spindle of the wheel that carries the small hand of the clock, with 2 brass pins soldered on the outer face, just long enough to project through the face of the clock to turn the disc round with. *b* is a piece of brass wire about ⅛ in. thick, screwed at one end about 1 in. down, and with 3 nuts fitted; the other part is hammered flat, to form a spring, and filed down to the required stiffness, which of course must not be great. The end that presses on the edge of the disc has a

small notch cut in to prevent slipping. *c* is another brass wire, same thickness as *b*, with 3 nuts, and bent as in sketch. Take off the clock face and hands, bore 2 holes through the side of clock-case, one above the disc and the other below, as shown; then by means of 2 nuts fix each wire in position; the other nut serves to connect the wires from battery. All is hidden when the face is put on. A small piece of platinum should be soldered on the spring *b*, where it drops on *c*, also a piece on the end of *c* to form more perfect connection. The action is thus:—Suppose 6 o'clock is the time you require to rise in the morning: at 6 o'clock in the evening, turn the disc round by means of the pins until the spring drops into the notch and falls on *c*; the connection is then made. As the clock moves, the disc raises *b* until 6 o'clock A.M., when it drops, and sets the bell ringing. The clock may be in the kitchen, and the wires go through ceiling to bell hanging on wall in bedroom. A simple break is made thus:—Solder a small plate with 2 screw-holes on 3 in. of ¼-in. brass tube, and nail it to the wall in bedroom; then put a small piece of cork in the bottom of tube, cut one of the wires from battery, file one end to a point, and push it up a short way through the cork; to the other wire, solder 8 in. of gilt picture cord with a brass wire 3 in. long soldered to the other end of picture cord, then pour a small quantity of mercury into the tube. When retiring for the night, merely wind up the clock, and put the brass wire at end of picture cord into the tube, which forms the connection. When the bell rings in the morning, take the wire out of tube, which breaks connection. Gilt picture cord forms good flexible connections to the clock; solder about 8 in. to end of each wire.

(4) Put 2 pins in the minute-wheel, and let them lift a light spring; this will give a contact-maker every half-hour. Then a pin on the hour-wheel to suit each hour that a signal is wanted for. Count the teeth, and divide that number by 12, thus having so many teeth for each hour. Mark one tooth "12," and at equal distances others "1," "2," &c. Miss pins at hours not wanted, and where a half-hour signal is needed, insert a pin half-way between the hours. The arrangement is shown in Fig. 26:

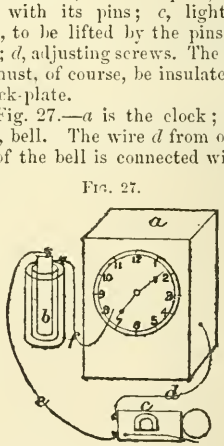
FIG. 26.



a, minute-wheel, with its 2 pins; *b*, hour-wheel, with its pins; *c*, light brass springs, to be lifted by the pins in the wheels; *d*, adjusting screws. The spring-studs must, of course, be insulated from the clock-plate.

(5) Fig. 27.—*a* is the clock; *b*, battery; *c*, bell. The wire *d* from one terminal of the bell is connected with any

FIG. 27.

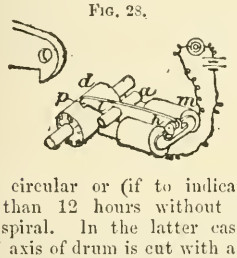


part of the works behind the clock; the wire *e* leads from the battery to the other terminal of the bell; and the wire *f* is placed at whatever hour the bell is wanted to ring. *f* has a little crook at the end, so that, when the hour hand of

the clock touches it, it is carried round with it, the bell continuing to ring till the crook detaches itself by the hand going round—*i.e.* about 3 hours. *f* is placed in such a manner that, although the hour hand touches it, the minute hand passes above it. This adjustment, though not so scientific as others, is equally successful.

Tell-tale Clock.—A drum *d* (Fig. 28) carries a strip of paper wound upon it. The surface has grooves cut in it,

FIG. 28.



either circular or (if to indicate for more than 12 hours without attention) spiral. In the latter case, one end of axis of drum is cut with a screw of the same pitch as the grooves on the drum, and works in a fixed nut, so that, when rotated, the drum travels along an axial line at such a rate that the grooves retain the same relative position to a fixed point, such as the indenting point, presently to be described. The drum has the hours engraved at one end, and is made to rotate once in 12 hours. A spring (not shown) holds the cylindrical armature off the face of electro-magnet *m* until a current passes, when the lever *l* is drawn down, and the point *p* makes a puncture in the paper. The position of this puncture relatively to lines drawn from the figures on end of drum along the paper in direction of drum's length, will indicate the time at which current passes. A simple contact spring, such as is used for ringing electric bells, is pushed by the watchman when making his rounds, and a record is made on the paper.

Batteries.—A galvanic battery consists of 2 electrical conducting bodies placed in a fluid which will exert greater chemical action on the one (the "positive element") than on the other (the "negative element"). The substances commonly used as elements are zinc opposed to carbon, cast iron, copper, platinum, and silver; while the usual chemical exciting fluids are nitric acid, sulphuric acid, copper sulphate, and potash bichromate. The positive element of the battery is at the same time its negative pole (or cathode), the former term applying only to the portion of the plate within the exciting fluid, while the latter denotes the portion outside the fluid. In the same way, the negative element is the positive pole (or anode).

The continuous arrangement of 2 or more cells, as just described, in a set, constitutes a compound battery. There are two ways of arranging the set, according as quantity or intensity of current is desired. In the former case, the anodes of all the single cells are attached to one wire, and the cathodes of all to another: the effect is then equal to the product of a single cell whose element surface corresponds to the sum of the surfaces in the single cells. To increase the intensity of the current, the anode of one cell is united to the cathode of the next, throughout the series, so that the current from each cell circulates through all. Other conditions being equal, the power of a battery is dependent upon the area of its negative element; and in making an intensity arrangement, it is very important that the negative elements of all the cells shall be of equal area, as the power will be regulated by the smallest negative element in the series.

The anode of a quantity battery is any part of the wire to which the anodes of the single cells are joined, the cathode in like manner being any part of the wire receiving the individual cathodes; but the anode of an intensity battery is the unconnected anode of the last cell of the series, and its cathode is that of the first cell. To apply a battery, the current is conveyed from each of its poles by means of electrically conducting wires arranged without interruption.

Making Batteries.—The construction of batteries may best be discussed in general terms before proceeding to ex-

plain the special features of the different forms of battery in use.

Zinc plates.—These generally constitute the positive elements by whose oxidation the current is produced. The best kind is "rolled Belgian," about $\frac{3}{16}$ in. thick, and costing something like 4*d.* a lb. New plates are coated with a greasy film, which needs dissolving off with caustic soda solution. This done, pieces of the required size are cut off by making a deep incision on each side, and letting mercury rest on the line, which it soon penetrates sufficiently to facilitate breaking the plate by bending over an edge. Cylinders may be formed by placing the plate in hot water, and curling it round a wooden roller.

The plates for some batteries (e.g. Bunsen's, Callan's, Grove's, Smee's), used to be amalgamated with mercury when the battery is made, and re-amalgamated subsequently at intervals. The amalgamation is performed by laying the plate in sulphuric acid of the same strength as the exciting fluid, and allowing it to remain some minutes. It is then taken out, and, while wet, has a globule or two of mercury rubbed over its face and edges, so that it may present a uniform silvered appearance. This is to prevent "local action:" its necessity may be thus exemplified. If a piece of unamalgamated zinc be put into dilute sulphuric acid, the surface will be immediately covered with minute bubbles of hydrogen, and the acid solution will soon become in a state of effervescence. This will go on until the zinc is dissolved, or the solution is saturated with zinc sulphate. On the amalgamated plate no action of this kind will take place; the smoothness of surface communicated by the mercury appears to cause the hydrogen first evolved to adhere to the plate, which is thus protected from any further action. This immunity only exists while the plate is detached from the other part of the battery, or the circuit between anode and cathode is severed. When the plate is in place, and the circuit is completed, the mercury affords no protection, as the hydrogen then is evolved at the negative element. When zinc plates, after being washed, look black in parts, they need re-amalgamating. (Dyer.)

The prepared plate is provided with one of the various forms of binding-screw, or has a strap of sheet copper, 5 in. long and uniform in width, soldered to it. The attachment is best effected by drilling a hole through both plate and strap, and firmly riveting; the strap must be clean at the joint, and the latter may be preserved from the action of the acid by a coat of varnish. For soldering a joint, use soft solder, zinc chloride solution for the flux (or rosin for copper to copper or brass), and a "tinning iron."

Negative elements.—These vary with the kind of battery, as described hereafter.

Exciting fluids.—The same remark applies here.

Separating the elements.—Obviously the positive and negative elements of a battery must not be in contact within the exciting fluid; they should be separated by a space of $\frac{3}{4}$ to $\frac{1}{2}$ in. In the case of batteries without porous cells, periodical attention will need to be given to ensure this condition being maintained.

Cells.—Containing cells are made to hold $\frac{1}{2}$ pint to 1 gal. Single-liquid cells have but 1 containing vessel; double ones have 2. Outer cells are made, as a rule, of glazed earthenware, though glass may be used; porous cells, of unglazed earthenware. The latter are put inside the zinc cylinder, or U-plate, and generally contain the positive element. Such cells should not be too hard and dense, nor the thickness of the sides exceed $\frac{3}{16}$ in. The softest are of red ware; but better cells, and sufficiently porous, are made from white clay. A test of the porosity is made by placing water in the cells, and allowing them to stand for about 15 minutes: if then no dew appears on the outside of the cell, it is probably too hard or thick, and will offer too great a resistance to the current; while if the water actually runs off the side, the cell is too porous,

and will shorten the period of action of the battery by too rapid transfusion of the liquids into each other. One-liquid cells, though convenient for short experiments, rapidly acquire a film of gas upon their negative plates, whereby the development of the current is impeded; consequently such cells, unless the excitant is agitated in some way, are unfit for supplying current for a length of time. This fault is termed "polarization." In two-liquid cells, the negative plate is surrounded by a liquid rich in oxygen (e.g. nitric acid in Grove's), which absorbs the hydrogen liberated at the negative plate, and keeps the latter free from film. But two-liquid cells are more troublesome. (Urquhart and Webb.)

Following are the most common forms of battery.

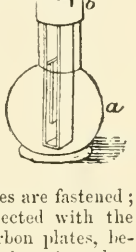
Antimonized Carbon.—Antimony is precipitated on the carbon cells described on p. 84, and in conjunction with these are used unamalgamated zinc rods and a solution of ammonium chloride. Such a battery may be useful for general laboratory purposes, being somewhat similar to Smee's in action, but with much cheaper negative elements, and a more economical utilization of the zinc. The carbon cells can be made small enough to be nearly close to the zinc, while, by having the containing vessels of ample size, the constancy of the current is enhanced.

Another form of this battery may be made with larger carbons and porous diaphragms, using for the outer liquid a mixture of antimonious chloride and ammonium chloride.

Plaster of Paris diaphragms can easily be made with dry plaster in the following manner:— Provide an inner core or mould of turned wood, a little tapering, and with a shoulder the thickness of the required diaphragm; round this tie 2 thicknesses of stout blotting-paper, well shake down the dry plaster between the wooden core and the paper, and immerse the whole in water. In a few minutes the diaphragm will be solid, and can be removed from the mould. (Symons, *Rep. Brit. Assoc.*)

Bichromate.—Bichromate batteries of bottle shape as in Fig. 29, with 2 carbon plates, a sliding rod and movable zinc plate, are very extensively used by experimenters and lecturers, because they are always ready for being put to work with one motion of the hand, not necessitating any other preparation; and as soon as the desired result is obtained, the battery can be put out of action with the same facility. *a* is the bottle; *b*, a brass cap for the top; *c*, a disc of ebonite, to which the carbon plates are fastened; *d*, a binding-screw, connected with the 2 fixed and parallel carbon plates, between which is suspended a zinc plate of about half the length. This plate of zinc is fixed on a brass rod, whose extremity is shown at *f*, made to slide up and down in a brass tube, which is either close-fitting and split, or loosely fitting and provided with a set-screw. In either case, it must be connected, by means of a copper band, with the terminal *e*. The excitant is a saturated solution of potash bichromate, to which is added $\frac{1}{10}$ volume of sulphuric acid; another $\frac{1}{10}$ should be added after the battery has worked for some time, when it begins to become weaker in action. For all purposes where a strong current is required at intervals, such as the working of induction coils, medical coils, small electromagnetic machines, and laboratory experiments, this battery is by many preferred to all others. The prices of such batteries range from 6*s.* 6*d.* to 24*s.*, according to the sizes and number of the plates, 3 carbons and 2 zincs being employed in the largest apparatus of the kind. Amateurs can hardly make this kind of battery so cheaply as it can be bought, because the bottles are high in price unless ordered in large numbers at a time.

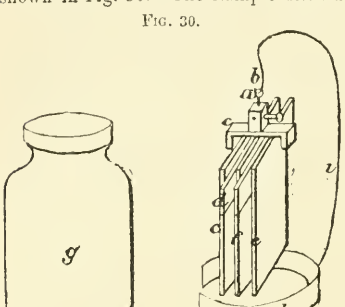
Fig. 29.



For this reason, Wiesendanger has devised a form of bichromate battery

having all the advantages of the one described above, and which can be made by amateurs at a fraction of the prices quoted. To make such a battery, take a marmalade jar *g*, measuring inside about 5 in. by 2½ in. diameter at the top. Get 2 plates of carbon, each 5 in. by 2¼ in., and a zinc plate (with terminals) of the same dimensions. Cut 2 pieces of thin mahogany board, 3 in. by ½ in. by ⅛ in., and a clamp *c*, such as shown in Fig. 30. The clamp *c* should

FIG. 30.



have a ring *a*, at the top, so that it can be suspended from the hook *b*, when the battery is not in actual use. The 2 pieces of wood *d* are put right and left to the top of the zinc plate *f*, as shown, the 2 carbons *e* to the right and left of the pieces of wood, and the whole arrangement is clamped by means of the top-clamp *c*. The frame can be made with a piece of bent brass strip *h*, 9 in. × ½ in. × $\frac{1}{16}$ in., to which the upright brass rod *i* is soldered; or it can be made of stout brass wire, No. 7, altogether. In either case, there will be so much elasticity in the ring *h*, that it can easily be put on, and will hold firmly on the top of the jar. This frame can be bought ready made for 10*d*. When the battery is to be used, the plates are inside the jar and in the liquid, supported by the projecting ends of the wooden pieces *d*; when out of use, the plates are lifted and suspended from the hook *b*, by means of the ring *a*, at the top of the terminal clamp. (Wiesendanger.)

Trouvé has considerably improved the bichromate battery by supersaturating the exciting fluid. He takes 24 dr. of potash bichromate powder to 1 pint water, and adds, after shaking, drop by drop, 63 dr. sulphuric acid. The liquid warms, and the salt dissolves. No crystals form on cooling, nor are chrome-alum crystals deposited in the cell. With 12 elements and the foregoing solution, 10 incandescent lamps can be kept going for 5 hours, each lamp being equal to 10 candles. The electromotive force of the cell is 2 volts with fresh solution, and the intensity of the current at the beginning on a short circuit is 118 ampères. The resistance is 0·07 ohm; 4 batteries working a Gramme machine have produced 14 kilogrammeters of work during 3 hours without weakening in power.

A test of Trouvé's battery has been made by Hospitalier with 2 sets of 6 cells each. The cells are of ebonite, and are arranged in a box or trough in such a manner that they can be easily removed—one side of the trough being hinged so that the cells can be slid out when the plates are drawn out of the solution. The elements are connected in series, the zinc of one cell being coupled to the 2 carbons of the next, and a winch and ratchet enables the plates to be wound up out of the solution, or to be immersed to any desired extent. The ebonite cells are no larger than is absolutely necessary, and the quantity of solution required for a battery of 6 is given by Hospitalier as 17·6 lb. water, 2·64 lb. powdered bichromate of potash, and 8 lb. sulphuric acid. This gives 5¼ oz. bichromate per 1¾ pint of water, or a solution half as strong again as that used by Poggendorf. Trouvé uses a much stronger solution on certain occasions. Care must be taken not to use a wooden stirrer, as that would be carbonised, to the injury of the solution. The total weight of a battery of 6 cells is said to be 74 lb. In the experiments made by Hospitalier, 2 batteries of 12 elements together were connected in series, and used to work 6 Swan lamps, the difference of poten-

tial at the terminals being, batteries 16·70 volts, lamps 14·15 volts. That was during the constant phase, for at the moment of immersion of the plates, there is great initial E.M.F. which produces a current of 12 ampères, and the object was to maintain a constant current of 8 ampères. The zincs were immersed at first to about $\frac{1}{3}$ in., and after a few minutes the current reached its normal strength of 8 ampères. After $\frac{1}{4}$ hour the batteries had settled to steady work, and for $1\frac{1}{2}$ hour the zincs were not lowered. After that time, the decrease in the delivery was compensated by gradually increasing the immersed surface. By this means, for nearly $4\frac{1}{2}$ hours the variation did not exceed $\frac{1}{2}$ ampère, but after that time the zincs were immersed to the full extent of nearly 6 in , and the current gradually fell, until, at the end of $5\frac{3}{4}$ hours, it had reached 5 ampères, and the experiment ceased. The result shows that each battery practically furnished $\frac{1}{2}$ h.p.-hour, the consumption of zinc being 365 dr., bichromate 600 dr., and sulphuric acid 1800 dr. The h.p.-hour is 1,980,000 foot-pounds, and as that was practically obtained with the consumption stated, an estimate of the cost can be easily calculated. Hospitalier states that 5 batteries, of 6 cells each, would suffice to support for 5 hours an arc lamp having carbons fully $\frac{1}{3}$ in. in diameter, with a current of 7 ampères, and a difference of potential of 40 volts at the terminals of the arc. No attempt was made to reduce the weight of the two batteries employed, which was 148 lb.; but, according to Hospitalier, it would be easy to construct 2 batteries of equal power to weigh not more than 110 lb., or considerably less than an accumulator capable of containing an equal amount of energy.

In working bichromate batteries, never place or leave the zincs in the excitant when the current is not needed; remove them the instant the battery is out of use; and, when in use, do not let them rest in the fluid for 5 minutes without disturbing either the plates or the fluid. The great defect of these batteries is the want of circulation in the fluid, and consequent decrease of the current. By applying heat sufficient to cause agitation, the current will retain its vigour almost till the solution is exhausted. Spent fluid may be evaporated down to recover the chrome-alum usually formed. A very convenient form of compound bichromate battery, is to have the plates attached at top to a support which can be raised by allowing it to depend by strings from a spindle; on revolving the latter, the strings coil on the spindle and raise all the plates at once. As to the number of bichromate cells required to give an electric light: 6 1-qt. cells will give a small light; 12 yield more than double; 24 afford a true voltaic arc and a brilliant light; 50 produce a light of 1500 candle power. Up to 50 1-qt. cells it is best to connect in series; any greater number should form a separate parallel circuit; and, finally, the negative wire from each series is led to one screw of the lamp and the positives to the other. By this arrangement, the electromotive force of the battery is not increased (that of 50 cells being usually enough), while the resistance of the elements that are doubled is halved. The guiding rule for grouping a given number of elements is to effect it so that the internal resistance shall equal the external. Not more than $\frac{1}{2}$ hour's continuous light can be got from any bichromate battery. (Urquhart and Webb.)

A voltaic generator, based on a modification of Dr. Byrne's negative plate cells, has been devised by Urquhart, and is described by him as being inexpensive, easily managed, certain in results, cheaply maintained, and very portable. It is simply a potash bichromate cell with negative plates of peculiar construction, and so arranged that a powerful current may be obtained from even 6 cells by the aid of abundant agitation. He thus describes its construction.

Each negative element consists of a copper plate, to one surface of which, as

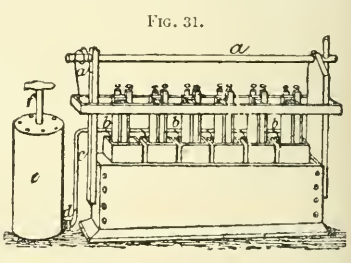
well as to its edges, a sheet of compact platinum foil, free from pin-holes, is soldered, and to the opposite surface a sheet of lead—the three metals being so united that the copper is protected from the action of acids. The leaden back and edges are then coated with asphaltum varnish or an acid-proof cement; and lastly, the platinum face, being first rubbed over gently with emery cloth, is thoroughly platinised.

To effect this, fill a containing-vessel and a porous cell with acidulated water, and place the porous cell within the large vessel. Tie a strip of zinc by a clean wire to the plate to be platinised; dip the zinc in the porous cell, and the plate in the outer cell, and drop into the outer cell, while stirring, a solution of platinic chloride in water: add it drop by drop, with agitation, until the platinum surface is seen to turn dark, and to have acquired a granular deposit of platinum. Upon this surface depends to a great degree the power of the generator. If any difficulty is experienced in securing a good deposit, dip only a little of the zinc in the solution at first, and increase as the coating is seen to form. Dry carefully, and do not scratch the plate or remove the deposit, as easily happens before it is dry. Each cell contains 2 such plates, between which a single zinc is suspended; and when the elements are immersed so that the exciting fluid reaches to within 1 in. of the top, a large negative surface is brought into action. Thus the platinum alone is the negative, and the copper core is a conducting body merely; while the lead, being almost passive, serves no other purpose than to protect the copper, so that another (best, a non-metallic) substance capable of resisting the action of bichromate solutions, might, with advantage, replace it. The exciting solution used in this cell is prepared as follows:—

Potash bichromate . .	2 oz.
Warm water	1 pint.
Sulphuric acid, when cool .	4 oz.

Fig. 31 represents a 6-cell generator of this kind. The ordinary, brown, glazed earthenware, oblong cells should be capable of containing at least 1 pint of the liquid; quarts will be found more economical. There are 3 plates in each cell—2 platinized, and 1 amalgamated zinc between. They are separated at the top edges by slips of wood or ebonite, against which they are securely clamped by stout brass clamps as shown. Thus the brass clamp, being in metallic contact with the lead, with clean scraped surface, represents them both as the positive pole. To the zinc plate in the centre is soldered a common binding-screw. Very stout, soft copper wires, about No. 12, are used to connect the elements in series (zinc to platinum), with clean

FIG. 31.



contacts. The sets of plates are fastened to a wooden framing, made to slide up and down the side uprights, by means of shaft, cords, and handle *a*, enabling the whole to be withdrawn from the excitant at one action. A ratchet and pawl keeps the plates in position. For quart cells the plates may be 8 in. long and 4½ in. wide. The air-distributing arrangements are as follow:—*b*, ½-in. leaden piping, fastened to the back of the framework, whence lead 6 ¼-in. rubber tubes, extending to the bottom of the cells, and running parallel with and directly under the plate edges; their ends are closed, and the horizontal portion is abundantly perforated; *c*, rubber pipe slipped over the end of *b*, its other end being made secure to the outlet *d* of a hand-pump *e* worked by the handle *f*. A valve at *d* closes the passage to *b* when the handle is drawn up, otherwise the solution would be

pumped out of the cells. The whole is screwed to the floor for steadiness. It is better to use a Fletcher's foot-blower.

If the elements are simply lowered into the solution, much greater power is obtainable from them than that given by zinc-carbon batteries. The full effect, however, can only be obtained by pumping in air by the small tubes. A great disturbance of the liquid results, and the current is so much augmented in power, that even a 6-cell battery will yield a light equal to that given by a 20-cell Bunsen or Grove. The air disturbance has no effect upon the electro-motive force of the battery, although the volume of current given off is enormously increased, and any other means of effecting the required agitation would probably answer the purpose equally well. The suggestion of Prof. Adams as to the air effecting a free circulation in the fluid, by which the metallic surfaces are kept constantly clear, is undoubtedly the correct explanation. The effects are in great part due to the low internal resistance of the cell, owing to the peculiar arrangement of negative plate, partly to the rapid flow of air upwards through the liquid, and partly to the production of heat. The action of the air-flow is principally mechanical, but by hastening the combustion of the zinc it tends to generate heat, which in turn reduces the resistance. The mechanical action of the air removes from the neighbourhood of the negative plate the chrome-alum formed there, and from the surfaces of the zinc plate the zinc sulphate, and brings a fresh supply of solution constantly to the surfaces.

With a 10-cell battery a 32-in. long platinum wire of No. 14 gauge (·089-in. diameter) was gradually brought to glowing red heat, which ebbed and flowed with the cessation or renewal of the air-flow. A brilliant electric light is maintained between 2 carbon points, which similarly varies in intensity with the flow of air, so that it is important to pump the air in regularly; and when this can be done by a crank attached to a heavy fly-wheel, almost perfect regularity is secured. The effects which are ordinarily produced by 60 or 70 Grove or Bunsen cells are obtained from 10 cells of this battery. For every 15 minutes or so of electric light, the solution in the cells will be nearly exhausted. A 20-cell battery produces a very powerful current, which will be nearly constant if the air-flow is maintained continuously. (Urquhart and Webb.)

Bunsen's.—Bunsen's zinc-carbon battery is a modification of Grove's, the only difference from the latter being the substitution of carbon for platinum foil. The carbon rod or plate becomes brittle in time through the action of the battery, and should therefore not be too thin; this necessitates a much larger porous cell than in Grove's element, and makes the battery more bulky. It is, however, to be preferred to Grove's for (1) it is much less expensive, and (2) owners of Grove's battery experience that the valuable platinum plates offer a bad temptation to workmen, and at times disappear in a mysterious way.

In Fig. 32, A represents a single element of Bunsen's battery. *a* is the outer cell made of glass, earthenware, or vulcanite, the zinc-plate bent round, with a binding screw, *b*, at the top. *c*, a round porous cell, with a wooden lid at the top, through which a carbon stick or rod passes; another binding-screw *d* is attached to the top of the carbon-rod. The wooden lid at the top is not absolutely necessary; instead of it, a clamp binding-screw may be fixed at the top of the carbon (see B). Carbon is a very porous substance; if the top is not protected, the acid will rise in it by capillary attraction, and soon destroy metallic fixtures by oxidation. For this reason, the top of each carbon plate or rod should, before being first used, be soaked in hot melted paraffin wax.

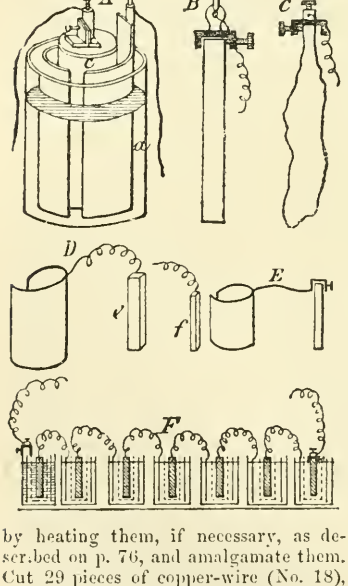
If artificial carbon is used, it is put in the outer cell and shaped like Z, in Fig. 32. The carbon rod described need not be carefully squared up—it may be of very irregular shape; pieces of the hard coke obtained as scurf in gas retorts are sometimes employed, without being finished up. If a battery is fitted

up with such pieces of carbon, the latter should be as nearly as possible of equal size.

Strongest nitric acid is put into the carbon cell, and acidulated water, 1 to 10, or 1 to 12, into the zinc cell. The action is similar to that in Grove's cell.

For making, at a low cost, a battery for producing electric light, buy 30 empty salt-jars at 2*d.* each, or 5*s.* the set; 30 round porous cells, 5 in. high and $2\frac{1}{2}$ in. diam., at 3*s.* to 4*s.* per dozen; 30 pieces of zinc, 10 in. by 5 in. by $\frac{1}{8}$ in. or $\frac{3}{16}$ in., ready cut, at 4*d.* to 5*d.* per lb. Bend the latter round as shown in Fig. 32.

FIG. 32.



by heating them, if necessary, as described on p. 76, and amalgamate them. Cut 29 pieces of copper-wire (No. 18), each 11 in. long. Buy also 30 pieces of carbon rod, 5 in. by $1\frac{1}{2}$ in. by 1 in., ready cut, and with a small hole drilled right through, $\frac{1}{2}$ in. from the top. If necessary, drill the holes in a lathe, or with an archimedian drill. Two plates, each $\frac{1}{2}$ in. thick, side by side, act better than a rod of double the thickness. The end of a piece of copper-wire is then passed through the top of the carbon, and twisted as shown in D. The other end of the same wire is soldered to the top of the zinc plate *c*. The wire may be coiled round a pencil, as shown at *f*. The wire connections and the soldered joints should be warmed, and then painted with three coats of Brunswick black, applied hot. The permanent wire connection from element to element described here considerably reduces the work and time expended in charging the battery. If parts of the battery are to be used at intervals for other purposes, clamps may be preferred; in that case, a strip of zinc is riveted to the top of the zinc plate, and clamped to the carbon of the next cell. The clamps required are sold at 4*s.* per dozen, but they can easily be made by amateurs.

To make battery clamp-screws, buy 1 lb. flat brass rod, $\frac{3}{4}$ in. wide and $\frac{1}{8}$ in. thick; $\frac{1}{2}$ lb. brass wire, No. 8 gauge; and $\frac{1}{4}$ lb. stamped hexagonal nuts. Cut a thread on the wire, and cut it in pieces of $\frac{7}{8}$ in.; tap the nuts, and either rivet or solder the threaded wire into the nuts; drill a hole at $\frac{1}{4}$ in. from one end of the brass rod, and similar holes at $2\frac{3}{4}$ in., $5\frac{1}{4}$ in., $7\frac{3}{4}$ in., &c., to the end of the rod, all holes being $2\frac{1}{2}$ in. apart. Tap all the holes. Bend the brass to shape in the vice, as shown in E; cut each clamp off, and fit the screws in. You can thus make your own clamps at about 1*d.* a piece, or less. They are just as good as those made from castings, but do not look quite so well finished. The 30 elements of the battery are connected as shown in F; clamp-binding screws are used for terminals.

Cost of the Materials for a 30-Element Bunsen's Battery for producing Electric Light.

	£	*s.*	*d.*
30 salt jars, 2*d.* each ..	0	5	0
30 porous pots, 4*d.* each	0	10	0
30 carbon rods, 5*d.* each	0	12	6
30 zincs, 9*d.* each ..	1	2	6
2 clamps	0	1	4
Mercury and wire ..	0	2	6
	£2	13	10

Of course 50 elements will give a better light than 30, and 100 a better one than 50, but a 30-element battery gives a very good light. It should always be borne in mind that one cell gives as much quantity as 50 of the same size, and that doubling the size of all the plates employed doubles the quantity; also that 50 elements will give 50 times the electro-motive force of one element. To produce light requires both as much quantity and as much electro-motive force as it is possible to obtain with batteries; the more of the latter, the longer will the spark be, and the more of the former, the broader the arc. (Wiesendanger.)

"With one exception, Bunsen's is the only real producer of voltaic currents that can be cheaply applied and depended upon in the production of electric light. Its current, once started, is almost constant for about 4 hours, and a good light may, with confidence, be depended upon for 3 hours." (Urquhart.)

An improvement upon the common practice of simply clamping the carbon by a binding-clamp of brass for the connection, is to give the block a heading of lead. Dry the head, cut a notch or two around it $\frac{1}{4}$ in. from the end; melt the lead, and pour it into some square mould; before it sets, dip in the carbon end; allow to solidify before removal. While still hot, the binding-screw may be soldered on, and, before it cools, the whole should receive a coating of melted pitch; or, better, dip the head in melted paraffin, which, when cool, will defend the connection from attacks of acid. A still better way, although not so quickly accomplished, is to electrotype a heading of copper upon the rods. Partly fill a porous pot with acidulated water; place in an outer cell containing crystals of copper sulphate dissolved in warm water. Heat the rods, and give them a coating of paraffin, driven in with a hot iron, between where the liquid will reach up to and the heading will reach to. If any paraffin spreads upon the end, drive it back by heating; cut a few notches in the head as before, and drill a hole through; in it tightly place a piece of stout copper wire, having $\frac{1}{4}$ in. of the end projecting at each side. Tie a wire around the carbon block; at the end fasten a strip of zinc, and place it in the porous cell, while the carbon head dips into the copper solution. Copper will begin to deposit upon the wire and carbon; when it has attained a thickness of good brown paper, remove the block, drill 2 holes through the copper and carbon, soak a little time in warm water, dry off, and place in melted paraffin. The binding-screw may be soldered to the copper, which will be found of great utility as a heading that is not attacked by acid.

When a "charge" is worked out, the outer acid is exhausted. The nitric acid will have assumed a reddish colour, and may be used again. Next time it turns green, and the third time quite clear, when it should be replaced by fresh.

While at work, this battery gives off fumes of nitric acid, which renders it necessary that it should be placed in a draught. The fumes are poisonous; and are worse while the porous cells are being emptied into the stock bottle.

In pulling the battery to pieces after operations, all connections are first loosened; the zincs are placed in a bucket of water to wash off the acid; the carbons are similarly treated; and the porous cells are emptied into the nitric acid stock bottle, and plunged into water. The outer liquid is thrown away as useless. Porous cells, once used, are kept in water for a few hours to soak out nitric acid or zinc sulphate. All connections are washed and dried, and examined for oxidized or bad-contact points, which must be scraped bright or filed.

The force of the Bunsen increases after setting up for about an hour, and the full effect is not attained until the acid soaks through the porous cell. Carbons are not affected, and last any length of time. The zinc is slowly consumed, through the mercury coating. 25 Bunsen cells will give a very brilliant light, and 50 will produce an arc of great power. The conducting wires must be about No. 12. (Urquhart and Webb.)

Callan's.—In the Callan's or Maynooth battery, a cast-iron vessel is used as the containing cell, and forms the negative element. A zinc plate, constituting the positive element, is placed in a porous cell within the iron cell. The excitant used in the iron cell is nitric acid, and that in the porous cell is dilute sulphuric acid (1 volume of vitriol to 7 of water). For experimenting, this battery is moderately cheap to construct, exposes a large negative surface, and evolves a powerful current; but it is costly in use from consuming so much nitric acid.

Carbon.—Mix together 15 parts powdered gas carbon, 3 of wood charcoal, and 10 of lump-sugar. Well shake down this powder, dry into paper moulds of the size and shape required, cylindrical being the most manageable. Bury the filled moulds in sand in a suitable iron or copper vessel, and gradually expose to a red heat. When cold, remove the burnt paper from the now solid cells, and soak them in a syrup made of equal parts lump-sugar and water. Well dry the cells, wrap them in paper, again bury in sand, and gradually expose them for some time to as strong a heat as practicable, but not less than a bright-red heat. For this purpose use may be made of an extempore furnace made of Fletcher's solid-flame burner, surmounted by a common unglazed earthenware drain-pipe, partially closed by an iron dome. The above described mixture, made with due care, does not crack as others do. (Symons, *Rep. Brit. Assoc.*)

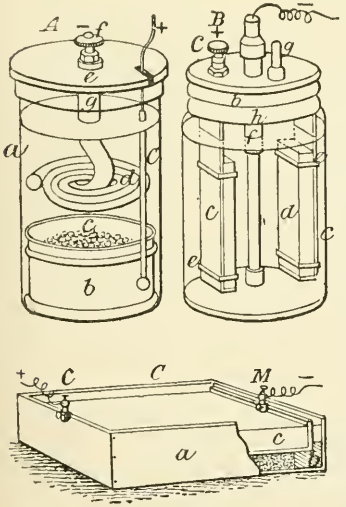
Ross has an improvement in the ordinary combination of zinc and carbon, in which the carbon-rod is packed around with broken coke. In the zinc compartment, the exciting solution is a 1-per cent. solution of sulphuric acid, or a 1½-per cent. solution of hydrochloric acid; while in the carbon cell is a mixed liquid composed of 1 volume hyponitric acid, 3 of sulphuric (or 4½ of hydrochloric) acid, and 4 of water. He also suggests nickel-plating, instead of amalgamating, the zincs.

André proposes carbon in the form of highly-burnt coke or wood charcoal, and in the shape of small pieces, separated from direct contact with the exciting liquid by an absorbent diaphragm. Salts of potassium, sodium, or ammonium, are used as the electrolyte. The zinc or iron electrodes are made in the form of tubes, and rest on wooden blocks surrounded by a tubular diaphragm, which allows the liquid to penetrate to the pieces of carbon in which the zinc or iron cells are imbedded. In another form, long strips of copper and zinc are coiled on a boss of wood, and separated by intervening pieces of indiarubber. The wheel or disc thus formed is revolved by an electro-motor, so that the exciting fluid does not cover more than half the disc at any one moment.

Copper Oxide.—Lalande and Chaperon have introduced a new battery with a single liquid and a solid depolarizing element, by associating copper oxide, caustic potash, and zinc. This battery possesses remarkable properties. Depolarizing electrodes are easily formed of copper oxide; it is enough to keep it in contact with a plate or cell of iron or copper constituting the positive pole of the element. Fig. 33 represents a very simple arrangement. At the bottom of a glass jar *a* is placed a box of sheet iron *b*, containing copper oxide *c*. To this box is attached a copper wire insulated from the zinc by a piece of indiarubber tube. The zinc is formed of a thick wire of this metal coiled in the form of a flat spiral *d*, and suspended from a cover *e*, which carries a terminal *f*, connected with the zinc; an indiarubber tube *g* covers the zinc at the place where it dips into the liquid, to prevent its being eaten away at this level. The jar is filled with a solution containing 30 or 40 per cent. of potash. This arrangement is similar to that of a Callan element, with this difference, that the depolarizing element is solid and insoluble. To prevent the inconveniences of the manipulation of the potash, a quantity of this substance, in the solid state necessary for an element, is enclosed in the box which receives

the copper oxide, and is furnished with a cover supported by a ring of caoutchouc. It suffices then for working the battery to open the box of potash, to place it at the bottom of the jar, and to add water to dissolve the potash; then pour in the copper oxide enclosed in a bag. Also the copper oxide forms very conveniently into blocks: thus, mix the copper oxide with magnesium oxychloride in the form of paste, so as to convert the whole into a thick mass, and introduce it into metal boxes. The mass sets in a short time, or very rapidly by the action of heat, and gives porous blocks of a solidity increasing with the quantity of cement employed (5 to 10 per cent.).

FIG. 33.



B represents an arrangement with blocks. The jar *a* is provided with a copper cover *b*, screwing into the glass. This cover carries 2 vertical plates of sheet iron *c*, against which are fixed the prismatic blocks *d*, by means of india-rubber bands *e*. The terminal C, carried by the cover, constitutes the positive pole. The zinc is formed of a single pencil *f*, passing into a tube fixed to the centre of the cover. The indiarubber is folded back upon this tube so as to make an air-tight joint. The cover carries, besides, another tube *g*, covered by a split indiarubber tube, which forms a safety-valve. The closing is made hermetical by means of an indiarubber tube *h*, which presses against the glass and the cover. The potash to charge the element is in pieces, and is contained either in the glass jar itself or in a separate box of sheet iron. Applying the same arrangement, hermetically-sealed elements are formed with a single plate of very small size. The employment of cells of iron, cast iron, or copper, which are not attacked by the exciting liquid, allows the easy construction of elements exposing a large surface C.

The cell *a*, forming the positive pole of the battery, is of iron plate brazed upon vertical supports; it is 14 in. long by 7 in. wide, and about $3\frac{1}{2}$ in. high. The bottom is covered with a layer of copper oxide, and in the 4 corners are porcelain insulators *b*, which support a horizontal zinc plate *c*, raised at one end and kept at a distance from the copper oxide and from the metal walls of the cell; $\frac{3}{4}$ of this is filled with a solution of potash. The terminals C and M, fixed respectively to the iron cell and to the zinc, serve to attach the leading wires. To avoid the too rapid absorption of the carbonic acid of the air by the large exposed surface, cover it with a thin layer of heavy petroleum (a substance uninflammable and without smell), or, better still, furnish the battery with a cover. These elements are easily packed so as to occupy little space.

Following are the principal properties of the battery. As a battery with a solid depolarizing element, it presents the advantages of only consuming its elements in proportion to its working; amalgamated zinc and copper are, in fact, not attacked by the alkaline solution; it is therefore durable. Its electromotive force is very nearly one volt. Its internal resistance is very low, $\frac{1}{3}$ or $\frac{1}{4}$ ohm for polar surfaces 4 in.

square, separated by a distance of 1½ in.; the rendering of these couples is considerable: the small cells shown in A B give about 2 ampères in short circuit, the large one gives 16 to 20 ampères. Two of these elements can replace a large Bunsen cell. They are remarkably constant. With a depolarizing surface double that of the zinc, the battery will work without notable polarization, and almost until completely exhausted, even under the most unfavourable conditions. The transformation of the products, the change of the alkali into an alkaline salt of zinc, does not perceptibly vary the internal resistance. This great constancy is chiefly due to the progressive reduction of the depolarizing electrode to the state of very conductive metal, which augments its conductivity and its depolarizing power. The manganese peroxide, which forms the base of an excellent battery for giving a small rendering, possesses at first better conductivity than copper oxide, but this property is lost by reduction and transformation into lower oxides. It follows that the copper battery will give a very large quantity of electricity working through low resistances, whilst under these conditions manganese batteries are rapidly polarized.

The energy contained in a copper oxide and potash battery is very great, and far superior to that stored by an accumulator of the same weight; but the rendering is much less rapid. Potash may be employed in concentrated solution at 30, 40, 60 per cent.; solid potash can dissolve the zinc oxide furnished by a weight of zinc more than ⅓ of its own weight. The quantity of copper oxide to be employed exceeds by nearly ¼ the weight of zinc which enters into action. These data allow of the reduction of the necessary substances to a very small relative weight.

The copper oxide batteries have given interesting results in their application to telephones. For theatrical purposes, the same battery may be employed during the whole performance, instead of 4 or 5 batteries. Their durability is considerable; 3 elements will work continuously, night and day, Edison's carbon microphones for more than 4 months without sensible loss of power. The elements will work for 100 hours through low resistances, and can be worked at any moment—after several months, for example; it is only necessary to protect them by a cover from the action of the carbonic acid of the atmosphere. Potash is preferable to soda for ordinary batteries, notwithstanding its price and its higher equivalent, because it does not produce, like soda, creeping salts. Various modes of regeneration render this battery very economical. The deposited copper absorbs oxygen pretty readily by simple exposure to damp air, and can be used again. An oxidizing flame produces the same result very rapidly. Lastly, by treating the exhausted battery as an accumulator—that is to say, by passing a current through it in the opposite direction—the various products are restored to their original condition; the copper absorbs oxygen, and the alkali is restored, whilst the zinc is deposited; but the spongy state of the deposited zinc necessitates its being submitted to a process, or to its being received upon a mercury support. Again, the copper oxide employed being a waste product of brazing and plate works, unless it be reduced, loses nothing of its value by its reduction in the battery; the depolarization may therefore be considered as costing scarcely anything.

With reference to this battery, Hospitalier gives the following account of a trial made with a cell weighing 1914 *grm.* and containing 200 *grm.* of copper oxide and 800 *grm.* commercial solution of potash at 40 per cent. The E.M.F. 1 hour after setting up was 0·98 volt, and the cell was put in circuit for 6 whole days through a resistance of 0·8 ohm. The current supplied was, on an average, ½ ampère during 6 days, or 518,400 seconds. The total quantity of electricity supplied was 259,000 coulombs, the weight of zinc consumed 88 grm., which corresponds to a theoretical

production of 260,000 coulombs. This is a most important point, and very favourable to the battery, for it shows that the local action is practically nil. The energy that the battery is capable of supplying is therefore available at will, without it being necessary to disturb the elements in order to withdraw the zinc from the liquid, as in the potash bichromate batteries, for example. The useful available rendering is 0·02 kilogrammetre per second. In 6 days, therefore, the battery supplied 10,368 kilogrammetres of available electrical energy. This exceeds the results obtained up to the present with accumulators of the same weight; but the supply is much slower than from these latter. It is, however, easy to increase this rendering by increasing the surface of the elements and by diminishing the distance of the oxide from the zinc plate. The result then increases more rapidly than the weight, and tends to approach that of the accumulators. The remarkable constancy of the rendering must be attributed chiefly to the fact that the product of the reduction is metallic copper, which is a good conductor, and that the solution of an alkaline salt of zinc which is formed presents a conductivity almost equal to that of the solution of potash. For a given weight of zinc dissolved, about 3 times the amount of solid potash is required, and a quantity of copper oxide equal to 1·25 times the weight of the zinc.

Cruikshank's.—This battery consists of zinc and copper plates united in pairs, and fitting into grooves in a wooden trough, the space left between the pairs of plates accommodating the excitant. This latter is dilute sulphuric acid with a slight addition of nitric. The battery is used as a compound for medical and telegraphic purposes, but it is not very convenient.

Daniell's.—The Daniell battery consists of a copper cylinder containing another of porous earthenware, in which is placed a zinc rod; this latter forms the positive and the copper the negative element. The battery requires 2 excitants—a saturated solution of copper sulphate in the copper cylinder, and dilute sulphuric acid (1 volume oil of vitriol to 7 of water) in the porous cell. The walls of the latter keep the solutions separate, while allowing the electric current to pass through. The cathode and anode are formed by attaching binding screws to the zinc rod and copper cylinder. The battery requires no frame, is effective in use, constant, and gives a current of fair intensity. (Dyer.)

To construct a home-made Daniell cell, select a small round earthenware jar, such as is used for keeping preserves, and having lined the bottom with guttapercha, or some suitable cement, to the depth of $\frac{1}{4}$ in., fix upright in this a rod of zinc, of equal height with the jar, to which a length of copper wire has been attached by passing it through a hole drilled in the upper part of the zinc rod, or by soldering. Make a cylinder of pipeclay, or other porous clay, larger than the zinc rod, and having dried it, make it hot in the fire by degrees, till it attains a red heat. Let this cylinder cool gently, and when cold, place it in the jar round the central rod, encircling it at a little distance. By moderately heating the end of the cylinder, it will, when placed on the guttapercha, make a groove which will fix the tube, and prevent infiltration of the fluids. Line the inside of the jar with a plate of thin copper, bent into a cylindrical form, and having a few holes punched in it, through which may be threaded the extremity of another length of copper wire. On the top of this cylinder place a flat ring of copper pierced with holes, and nearly, but not quite, touching the porous cylinder. This forms the battery. To charge it, a saturated solution of copper sulphate is poured between the copper and the clay tube, and some crystals of the same salt are placed upon the perforated ring so as just to be in contact with the solution. The zinc compartment is then filled with a solution of zinc sulphate, sal-ammoniac, or common salt. (*Electrician.*)

Granule carbon.—This battery con-

sists of an outer vessel *a* (Fig. 34), containing an inner porous cell *b*; in the outer vessel is a carbon plate *c*, packed round with broken gas-retort carbon; the zinc rod *d* is placed in the porous cell. A convenient battery may be made of 5 No. 9 jars, into which the carbon-plates with their binding-screws and the porous cells are placed; the outer cells being then filled up with granulated carbon to within 1 in. of the top. As to the mixture. Make a saturated solution of potash bichromate with cold water (you will find $\frac{3}{4}$ hour sufficient to make the solution strong enough, if you give it 2 or 3 stirrings); allow it to settle, and pour off the clear solution. Take a glazed earthenware pan, and mix in it sufficient of 2 parts of the above, with 1 of muriatic acid, and fill up the outer cells. For the inner cells, break up some ammonium chloride, and put $1\frac{1}{2}$ oz. into each cell, then 1 oz. muriatic acid into each, and fill up immediately with water to the level of the granulated carbon. Couple up with stout wire, and a good light will be the result, providing you select a lamp giving low resistance. The battery requires replenishing about every 6 or 8 weeks; but this need not be if you arrange to remove the zincs from the porous cells when the light is not required. The light gets fainter after 3 hours' constant work, but regains strength if a rest is given. A layer of mercury at the bottom of the porous cell assists in keeping the zinc amalgamated and in working order. About 5 cells 8 in. by 5 in. diameter will maintain a low-resistance Swan lamp of 5 candles' power for 40 hours, but the light will not be full 5 candles. The solutions for recharging do not cost more than 3*d.* to 6*d.* in 8 or 9 months, according to use. This battery can be sealed if used for medical coils, a testing cell, or firing fuses.

FIG. 34.

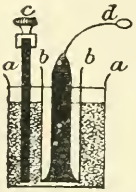
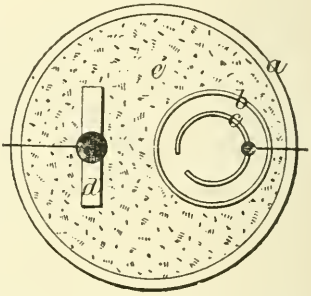


Fig. 35 shows a transverse section of a cell, which better illustrates the relative positions of the parts: *a*, outer cell; *b*, porous cell; *c*, zinc; *d*, carbon plate; *e*, granulated carbon. The black spots on the carbon-plate and zinc show the position of binding screws with wires attached. Couple up zinc of one cell to carbon of next, throughout, with

FIG. 35.

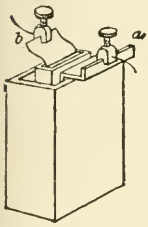


stout copper wire. Place the lamp opposite a looking-glass, to economize the light. The dimensions of some parts are: outer jars, 8 in. by 6; porous cells, 9 in. by $2\frac{1}{2}$; carbon plates, $8\frac{1}{2}$ in. by $2\frac{1}{4}$ by $\frac{3}{10}$; zinc tubes, 9 in. by $1\frac{3}{4}$. The battery may be used in a well-ventilated bedroom, but the muriatic acid might then be better replaced by sulphuric.

Grove's.—The elements of this battery are platinum for the negative and zinc for the positive. The battery requires a containing vessel to hold the entire arrangement, and an inner cell to hold the platinum foil only. This inner cell, like that in Daniell's battery, is of porous earthenware, which will permit the passage of the galvanic current through its sides, but will not allow the exciting fluids to mingle. When the zinc plate *a* is placed in the containing jar, the porous cell is placed between the upright portions of the zinc, and the platinum foil *b* is then put into the porous cell, as in Fig. 36. The zinc plate is usually made of a long strip bent up in the form of the letter U, by

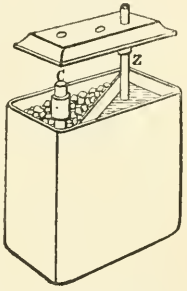
which means the zinc is brought opposite to each side of the platinum plate. But it is advantageous, instead of bending a long strip of zinc, to employ 3 shorter pieces: 1 to be put at the bottom of the containing jar, and 2 others resting on this to form the vertical sides. This is less expensive to make, and more economical to use. Binding-screws, attached to the zinc plate and the platinum, form the 2 electrodes. The excitants are strong nitric acid in the porous cell with the platinum, and acidulated water with the zinc. The form illustrated is most convenient on the score of portability, but the greatest power is obtained by arranging the battery in cylindrical vessels like a Bunsen. The ends and bottoms of porous cells may be thickened for strength. These batteries are expensive at first, owing to the high price of platinum; but the latter does not waste, and is best procured of reasonable stoutness at the outset. The connections may be soldered; but it is better to have a copper intermediary clamp-piece, and coat it with a protective against the acid fumes, e.g., Brunswick varnish, or an alcoholic solution of sealing-wax. The Grove battery costs about 3 times as much as a Bunsen of equal power; but its low resistance gives a stronger current for the same size. The connections and conductors must be of stout, soft copper; and the porous cells should have a lip at one corner. The duration of the battery about equals that of the Bunsen, with a smaller consumption of nitric acid.

FIG. 36.



Insulite.—The British Insulite Co. have brought out a sealed cell suitable for domestic use, as shown in Fig. 37. It is an oblong vessel on plan, with a diaphragm of porous material securely cemented to opposite corners, thus dividing the cell into 2 equal compartments. In one is a carbon rod surrounded by fragments of carbon about pea size, and in the other, the familiar zinc rod, with a special excitant, non-corrosive and non-poisonous. The lid is perforated with 3 holes, into 2 of which the electrodes fit water- and air-tight, by the aid of collars formed of pieces of rubber tubing; while the third is closed by a stopper and capsule, forming a release-valve to provide for the slight variations in the pressure of the contained air. When the capsule is screwed home, the cell may be shaken about or inverted without injury or escape of the liquid; and one turn of the capsule is sufficient to leave the cell in a permanently working condition. The lid, having been fitted to the electrodes, is pressed down on the diaphragm, and autogenously soldered in position, the zinc rod lasting about 2 years with the average amount of usage of the bell, and being readily replaced when worn out. The connections are made by nickel-plated caps, split and held by pinching screws to the carbon and zinc rods, and as the latter are tightly surrounded by rubber, there is little risk of defective connections from corrosion or other effects.

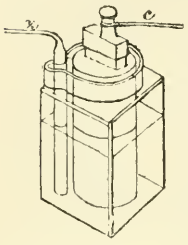
FIG. 37.



Leclanché.—This form of battery, Fig. 38, is in very general use for electric bells, its great recommendation being that, once charged, it retains its power without attention for several years. 2 jars are employed in its construction: the outer one is of glass, contains a zinc rod, and is charged with a solution of ammonium chloride (sal ammoniac). The inner jar is of porous earthenware, contains a carbon plate, and is filled up with a mixture of manganese peroxide and broken gas carbon. When the carbon plate and the zinc rod are connected, a steady current of elec-

tricity is set up, the chemical reaction which takes place being as follows:—The zinc becomes oxidized by the oxygen from the manganese peroxide, and is subsequently converted into zinc chloride by the action of the sal-ammoniac. After the battery has been in continuous use for some hours, the manganese becomes exhausted of oxygen, and the force of the electrical current is greatly diminished; but if the battery be allowed to rest for a short time, the manganese obtains a fresh supply of oxygen from the atmosphere, and is again fit for use. After about 18 months' work, the glass cell will probably require recharging with sal-ammoniac, and the zinc rod may also need renewing; but should the porous cell get out of order, it is better to get a new one entirely, than to attempt to recharge it. (Dyer.)

FIG. 38.



Lime Chromate.—This is a double-liquid battery devised by Fitzgerald and Molloy; it is said to be as constant as the Bunsen, almost as effective, and much cheaper. The chief point is to secure a large negative surface, and, by a soft porous cell, to reduce the internal resistance. The best form is a carbon cylinder surrounding a large porous cell containing a zinc cylinder. The carbon for the cylinder must be ground to fine powder, mixed into a stiff dough with water and sugar syrup, baked until hard, plunged, while still hot, into a strong solution of sugar or tar, heated to whiteness, and cooled slowly. Another arrangement is as follows:—In a large soft porous cell is centrally placed a thin carbon or Bunsen rod, with a screw affixed. A quantity of broken carbon, in lumps as large as hazel-nuts, is packed around the rod. Melted pitch is run over the top, and a conical hole is left for the introduction of the liquid. The outer cell contains a zinc cylinder of only just sufficient diameter to admit the porous cell freely, the object being to have the zinc near the negative element. To allow the outer liquid greater freedom of action, the zinc cylinder has a separation of about $\frac{1}{2}$ in. The elements are thus carbon and zinc. The exciting solutions are:—(*a*) For porous cell: 2 oz. lime chromate, 5 oz. warm water, 5 oz. sulphuric acid. (*b*) For the outer cell: 1 pint water, 3 oz. sulphuric acid. Little or no fumes are given off. The electro-motive force is slightly greater than that of the Bunsen; but the internal resistance is also greater. The same cell is available for use with another excitant, which works with even greater force, and gives no fumes for the first 2 hours:—For the porous cell: 2 oz. potash bichromate, 10 oz. nitric acid, 2 oz. sulphuric acid. The solution in the outer cell is the same as for the Bunsen. This works with greater power than the Bunsen, owing to the arrangement of the carbon; the internal resistance is less, but the cost of working is rather greater. After use, the porous cells should be emptied of their contents, and kept in water till again wanted. The same solution may be used 2 or 3 times, and on any appearance of a paucity of potash salt, more should be added. The carbon cell demands a strongly acid mixture. The battery may be advantageously used as a Bunsen, and gives a better current than common forms at little extra cost of construction. (Urquhart.)

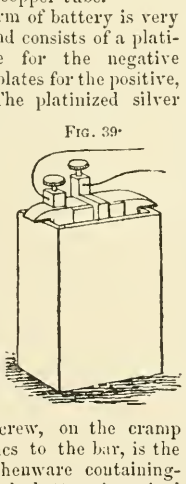
Silver Chloride.—Skrivanow, of Paris, covers a carbon plate on both sides with silver chloride, and immerses it in a solution of potassium or sodium hydrate, the hydrate being in the proportion of 30 to 40 per cent. of the weight of the water. A zinc plate is immersed in the same solution close to the carbon, which may, however, be wrapped in asbestos cloth or placed in a porous cell. The battery may be revivified by plunging the carbon plate in a bath composed of nitric and hydrochloric acids, or sodium chloride dissolved in water, the object being to chloridize the metallic

silver. The hydrates may be dissolved in glycerine if the battery is exposed to frost.

Amongst portable batteries may be noted one by Mackenzie, which is a modification of the silver chloride arrangement. A short piece of copper tube has one end stopped by a cap of the same metal, and, the interior being plated with silver, is subsequently covered with a layer of fused silver chloride; the other end of the tube is closed with a cap of some insulating material, through which passes a zinc screw, holding in the interior of the tube a zinc cylinder or tube, extending nearly to the bottom of the cell thus formed. The exciting liquid is sodium chloride (common salt) or sulphate, or zinc chloride. The wires are attached respectively to the zinc screw and to the exterior of the copper tube.

Smee's.—This form of battery is very extensively used, and consists of a platinized silver plate for the negative element, with zinc plates for the positive, as in Fig. 39. The platinized silver plate is usually attached to a wooden bar, and the zinc plates, placed one on each side of it, are kept in position by a metallic cramp passing over the top of the bar. A binding screw, passed through the wooden bar and attached to the silver plate, forms the anode, and a similar binding screw, on the cramp that holds the zincs to the bar, is the cathode. An earthenware containing-vessel is required; the battery is excited by dilute sulphuric acid (7 volumes of water to one of acid). This battery is admirably adapted for electro-depositing and general galvanic experiments; but it is not suitable for producing electric light, nor for intensity coils. It is easily managed, tolerably constant, and requires only one exciting fluid: therefore, porous cells are dispensed with. (Dyer.)

FIG. 39.



Thermo-electric.—When the junction, of 2 different metals is heated, an electric current is generated, the greatest effect being obtained with antimony and bismuth. Such generators are known as thermo-electric piles. By multiplying them, increased force is produced; 60 well-constructed couples give a current equal to that from a 1-gal. Bunsen battery, and less than 3000 of Faure's couples, with an expenditure of 80 cub. ft. of gas per hour for heating, are equivalent to 50 Bunsen's. An improved form has recently been introduced by Sudre. One of its main features is the maintenance of the necessary difference of temperature between the two solderings of each couple by placing the couples between surfaces from which they are electrically insulated. An isolated thermo-electric couple is ordinarily composed of a metallic prism casting, and a polar plate of iron, copper, or German silver, soldered to each of its extremities. The plates do not interfere with the electric force obtained, and it is the bar (such as that of antimony and zinc) which produces the effect. When using 2 metals whose effects are combined, and which are easily fusible, *e g.* antimony and bismuth, the couple is formed of 2 bars, joined by a cross bar soldered to each. The total resistance of a couple is composed (1) of the resistance of the connecting plate; (2) of the resistance of the bar; (3) of a particular resistance at the points of contact or soldering between the plates and the bar. The plates should be of a sufficiently conductive metal, large and thick enough to present but feeble resistance, and as short as possible. The bar should have very little resistance under a small volume. Sudre takes as a datum the formula $R = k\frac{L}{S}$, in which k is a specific coefficient for the metal employed, L the length of the bar, and S its section. As the resistance depends on the ratio $\frac{L}{S}$, the volume of the couple may be

diminished by lessening the length and sectional area in equal degrees, in which case the resistance will not be affected. The length given to the bar depends upon the difference of temperatures employed. For differences between 10° and 120° C. (50° and 248° F.), Sudre gives the couples a length of ½ in., whilst if the higher temperature reaches 300° C. (572° F.), the length varies from ¾ to 1⅛ in. The resistance at the points of contact or soldering is of the highest importance. The junction should be made so that the plate is in contact with the whole section of the bar. The plate should penetrate to a very little depth within the bar, so as not to diminish the electro-motive force of the couple; for the effective difference of temperature is that of the 2 solderings, and this diminishes as the plates penetrate into the bar, and thus approach one another.

Residues.—From a table compiled by Kolb, one of the secretaries in the Imperial Telegraph Department of Germany, it seems that of the 12,350*l.* spent during the year 1881–82 upon the 127,166 galvanic cells in use, 2727*l.*, or about 22 per cent., were recovered by the sale of the battery residues, consisting of copper, zinc, and lead salts. It has been customary to sell these products by auction twice a year. The Government does not guarantee any fixed percentage of metal in these salts, but the amount varies very slightly. The normal cell of the German telegraph offices is a modified Daniell of a simple and cheap kind. The zinc electrode is formed of a ring, hanging down from the edge of a glass vessel to half its depth. On the bottom lies a rectangular plate of lead, to which a vertical stout iron wire, encased in sheet lead, is soldered, making the other electrode. The glass is filled with zinc sulphate solution, and a few crystals of copper sulphate are from time to time dropped into the liquid. Of these materials the zinc ring is, of course, most subject to deterioration. Thus the above-mentioned 127,166 cells require nearly 80,000 new zinc rings, against 730 lead sheets and 910 lead plates. The copper sulphate forms the largest item in the annual expenditure, amounting to 8000*l.* During the 4 years which the table comprises, from 1878 to 1882, the number of cells had increased by nearly 20,000. (*Engineering.*)

Bells.—An ordinary electric bell is merely a vibrating contact-breaker carrying a small hammer on its spring, which hammer strikes a bell placed within its reach as long as the vibration of the spring continues. The necessary apparatus comprises a battery to supply the force, wires to conduct it, circuit-closers to apply it, and bells to give it expression.

The Leclanché battery (see p. 89) is the best for all electric bell systems. On short circuits, 2 cells may suffice, increasing up to 4 or 6 as required. It is false economy to use a battery too weak to do its work properly. The battery should be placed where it will not be subject to changes of temperature, *e.g.*, in an underground cellar.

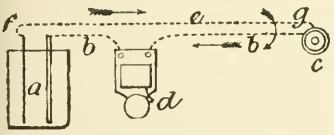
The circuit wire used in England for indoor situations is "No. 20" copper wire, covered with guttapercha and cotton. In America, "No. 18, first-class, braided, cotton-covered, office wire" is recommended, though smaller and cheaper kinds are often used. The wire should be laid with great regard to keeping it from damp, and ensuring its perfect insulation. Out of doors, for carrying long distances overhead, ordinary galvanized iron wire is well adapted, the gauge running from "No. 4" to "No. 14," according to conditions. Proper insulators on poles must be provided, avoiding all contact with foreign bodies; or a rubber-covered wire encased in lead may be run underground.

The circuit-closer, or means of instantaneously completing and interrupting the circuit, is generally a simple press-button. This consists of a little cylindrical box, provided in the centre with an ivory button, which is either (1) attached to a brass spring that is brought into contact with a brass plate

at the back of the box on pressing the button, or (2) is capable of pressing together 2 springs in the box. A wire from the battery is attached to the spring of the press-button, and another from the bell is secured to the brass plate. Platinum points should be provided on the spring and plate when the contact takes place. While the button is at rest, or out, the electric circuit is broken; but on being pressed in, it completes the circuit, and the bell rings.

The relative arrangement and connection of the several parts is shown in Fig. 40: *a*, Leclanché cell; *b*, wire;

FIG. 40.



c, press-button; *d*, bell. When the distance traversed is great, say ½ mile, the return wire *e* may be dispensed with, and replaced by what is known as the "earth circuit," established by attaching the terminals at *f* and *g* to copper plates sunk in the ground.

The bells used are generally vibrating ones, and those intended for internal house use need not have a higher resistance than 2 or 3 ohms. At other times, single-stroke and continuous-ringer bells have to be provided, the latter being arranged to continue ringing until specially stopped. The bell may or may not be fitted with an annunciator system; the latter is almost a necessity when many bells have to ring to the same place, as then 1 bell only is requisite. A single-stroke bell is simply a gong fixed to a board or frame, an electro-magnet, and an armature with a hammer at the end, arranged to strike the gong when the armature is attracted by the magnet. A vibrating bell has its armature fixed to a spring which presses against a contact-screw; the wire forming the circuit, entering at one binding-screw, goes to the magnet, which in turn is connected with the armature; thence the circuit continues through the contact-screw to the other binding-screw, and out. When set in motion by electricity, the magnet attracts the armature, and the hammer strikes the bell; but in its forward motion, the spring leaves the contact-screw, and thus the circuit is broken; the hammer then falls back, closing the circuit again, and so the action is continued *ad libitum*, and a rapid vibratory motion is produced, which makes a ringing by the action of the successive blows of the hammer on the gong.

The following useful hints on electric bell systems are condensed from Lockwood's handy little volume on telephones.

With regard to the battery, he advises to keep the sal-ammoniac solution strong, yet not to put so much in that it cannot dissolve. Be extremely careful to have all battery connections clean, bright, and mechanically tight, and to have no leak or short circuit. The batteries should last a year without further attention, and the glass jars never ought to be filled more than ¾ full.

(*a*) 1 *Bell and* 1 *Press-button.*—The simplest system is 1 bell operated by 1 press-button. The arrangement of this is the same whether the line be long or short. Set up the bell in the required place, with the gong down or up as may be chosen; fix press-button where wanted, taking all advantages offered by the plan of the house; *e.g.* a wall behind which is a closet is an excellent place to attach electrical fixtures, because then it is easy to run all the wires in the closets, and out of sight. Set up the battery in a convenient place, and, if possible, in an air-tight box. Calculate how much wire will be requisite, and measure it off, giving a liberal supply; joints in inside work are very objectionable, and only admissible where absolutely necessary. Cut off insulation from ends of wire where contact is to be made to a screw. Only 3 wires are necessary, *i.e.* (1) from 1 spring of the press-button to 1 pole of

the battery, say the carbon, (2) from the other spring of the button to 1 binding-screw of the bell, (3) from the other pole of the battery to the other binding-screw of the bell. In stripping wires, leave no ragged threads hanging; they get caught in the binding-screw, and interfere with the connection of the parts. After stripping the wire sufficiently, make the ends not only clean but bright. Never run 2 wires under 1 staple. A button-switch should be placed in the battery-circuit, and close to the battery, so that, to avoid leakage and accidental short circuiting when the bells are not used for some time, it may be opened.

(*b*) 1 *Bell and* 2 *Press-buttons.*—The next system is an arrangement of 2 press-buttons in different places to ring the same bell. Having fixed the bell and battery, and decided upon the positions of the 2 buttons, run the wires as follows:—1 long covered wire is run from 1 pole of the battery to 1 of the springs of the most distant press-button, and where this long wire approaches nearest to the other press-button it is stripped for about 1 in. and scraped clean; another wire, also stripped at its end, is wound carefully around the bared place, and the joint is covered with kerite tape; the other end of the piece of wire thus branched on is carried over and fastened to the spring of the second press-button. This constitutes a battery wire branching to 1 spring of each press-button. Then run a second wire from 1 of the bell binding-screws to the other spring of the most distant press-button, branching it in the same manner as the battery-wire to the other spring of the second button; connect the other pole of the battery to the second binding-screw of the bell, and the arrangement is complete—a continuous battery-circuit through the bell when either of the buttons is pressed. Before covering the joints with tape, it is well to solder them, using rosin as a flux.

(*c*) 2 *Bells and* 1 *Press-button.*—When it is required to have 2 bells in different places, to ring from 1 press-button at the same time, after erecting the bells, button, and battery, run a wire from the carbon pole of the battery and branch it in the manner described to 1 binding-screw of each bell; run a second wire from the zinc pole of the battery to 1 spring of the button, and a third wire from the other spring, branching it to the remaining binding-screw of both bells. It will not answer to connect 2 or more vibrating bells in circuit one after another, as the 2 circuit-breakers will not work in unison; they must always be branched, *i.e.* a portion of the main wire must be stripped, and another piece spliced to it, so as to make 2 ends.

(*d*) There are other methods, one of which is, if more than 1 bell is designed to ring steadily when the button is pressed, to let only 1 of the series be a vibrating bell, and the others single-strokes; these, if properly set up and adjusted, will continuously ring, because they are controlled by the rapid make and break of the 1 vibrator.

(*e*) *Annunciator system.*—To connect an indicating annunciator of any number of drops with a common bell, to be operated by press-buttons in different parts of a house, is a handy arrangement, as one drop may be operated from the front door, another from the drawing-room, a third from the dining-room, and so on. The annunciator is fastened up with the bell near it. All the electro-magnets in the annunciator are connected by 1 wire with 1 binding-screw of the bell, and the other binding-screw of the bell is connected with the zinc of the battery. It is a good plan to run a wire through the building from top to bottom, at one end connecting it with the carbon pole of the battery. It ought to be covered with a different coloured cotton from any other, so as to be readily identified as the wire from the carbon. Supposing there are 6 press-buttons, 1 in each room, run a wire from 1 of the springs of each of the press-buttons to the main wire from the carbon pole, and at the point of meeting strip the covering from both the main wire and the ends of the branch wires from the

press-buttons, and fasten each branch wire to the main wire, virtually bringing the carbon pole of the battery into every press-button. Next, lead a second wire from the other spring of each press-button to the annunciator screw-post belonging to the special drop desired. This will complete the circuit when any of the press-buttons is pushed; for, as each annunciator magnet is connected on 1 side to its own press-button, and on the other side to the common bell, it follows that when any button is pressed, the line of the current is from the carbon pole of the battery, through the points of the press-button, back to the annunciator, thence through the bell to the zinc pole of the battery; and that, therefore, the right annunciator must drop and the bell must ring. In handsome houses, run the wires under the floor as much as possible, and adopt such colours for wire covering as may be harmonious with the paper and paintings. Also test each wire separately, as soon as the connection is made.

(*f*) *Double system.*—A system of bells in which the signalling is done both ways, that is, in addition to the annunciator and bell located at one point, to be signalled by pressing the button in each room, a bell is likewise placed in each room, or in a certain room, whereon a return signal may be received—transmitted from a press-button near the annunciator. This is a double system, and involves additional wires. One battery may furnish all the current. Run the main carbon through the house, as before, in such a manner as to admit of branch wires being easily attached to it. Run a branch wire from it to the spring of one of the press-buttons, a second wire from the other spring of the same button to the screw-post of the bell in room No. 2, and from the other screw-post of the said bell to the zinc pole of the battery. This completes one circuit. The other is then arranged as follows:—The main carbon, besides being led, as already described, to the spring of the press-button in room No. 1, is continued to one of the binding-screws of the bell in the same room: the other terminal of that bell is carried to one spring of the press-button in room No. 2; the complementary spring of that press-button is then connected by a special and separate wire with the zinc of the battery, and the second circuit is then also completed.

An alternative method is to run branches from the main carbon wire to all the press-buttons, and from the main zinc wire to all the bells, connecting by separate wires the remaining bell terminals with the remaining press-button springs. In the latter plan, more wires are necessary. Although the connections of but one bell either way have been described, every addition must be carried out on the same principle.

When 2 points at some distance from one another, *e.g.* the house and a stable 100 yd. distant, are to be connected, it is easy to run 1 wire, and use an earth return. If gas or water pipes are in use at both points, no difficulty will be found in accomplishing this. A strap key will in this case be found advantageous as a substitute for a press-button. The connecting wire at each end is fastened to the stem of the key; the back contact or bridge of the key, against which when at rest the key presses, is connected at each end with 1 terminal of the bell, the other terminal of each bell being connected by wire with the ground. A sufficient amount of battery is placed at each point, and 1 pole of each battery is connected with the earth, the other pole being attached to the front contact of the strap key. If impossible to get a ground, the second terminal of both bell and battery at each end must be connected by a return wire.

(*g*) *Bell and Telephone.*—It is a very easy matter to add telephones to bell signaling appliances, when constructed as here described. The only additions necessary are a branch or return circuit for the telephones, and a switch operated by hand, whereby the main wire is switched from the bell return wire to the telephone return wire. A very simple plan for a bell-call and telephone line from one room to another, can be

made as follows: Apparatus required—2 bells, 2 telephones, 2 3-point switches, 2 strap-keys with back and front contacts, and 1 battery. Run 1 wire from the stem of the key in room No. 1 to the stem of the key in room No. 2. This is the main wire. Fix the bell and 3-point switch below it in each room. Connect the back contact of each key by wire to the lever of the 3-point switch, attach 1 of the points of the switch to 1 of the bell terminals, and the other bell terminal to a return wire. The return wire will now connect the second bell terminal in one room with the second bell in the other room. The other point of the switch in each room is now connected by a wire with 1 binding-screw of a telephone, and the other telephone screw is attached by another wire to the bell return. Connecting 1 pole of the battery also to the return wire, and the other pole to each of the front contacts of the keys, the system is complete. When at rest, each switch is turned on to the bell. To ring the bell in the other room, the key is pressed. The battery circuit is then from battery, front contact of the pressed key, stem of key, main wire, stem of distant key, switch, bell, and through return wire to the other pole of the battery. After bell signals are interchanged, the 3-point switches are transferred to the telephone point, and conversation can be maintained. (Lockwood.)

Making an Electric Bell.—The following description applies to 3 sizes—viz. for a 2-in. bell, hereafter called No. 1; 2¾-in., or No. 2; 4-in., or No. 3, which sizes are sufficient for most amateurs' purposes, and, if properly made, a No. 3 Leclanché cell will ring the largest 2 through over 100 yd. No. 24 (B. W. G.) wire.

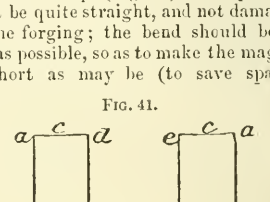
The Backboard and Cover.—This may be of any hard wood, by preference teak, oak, or mahogany, and if polished, so much the better; the size required will be—

No. 1, 5½ in. long,	3¾ in. wide,	½ in. thick.
No. 2, 7 in. „	3¾ in. „	¾ in. „
No. 3, 8½ in. „	5 in. „	¾ in. „

The cover must be deep enough to cover all the work, and reach to within about ¼ in. of the top and sides of back, and allow ⅜ in. to ¾ in. between the edge of bell and cover; the making of this had better be deferred until the bell is nearly complete.

The Electro-Magnet.—This should be of good round iron, and bent into a horse-shoe shape (Fig. 41). The part *a b* must be quite straight, and not damaged by the forging; the bend should be as flat as possible, so as to make the magnet as short as may be (to save space).

FIG. 41.



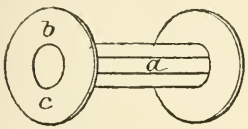
When made, the magnet is put into a clear fire, and when red hot, taken out and laid in the ashes to slowly cool; care must be taken not to burn it. Lastly, 2 small holes are drilled in the centre of the ends at *c*, about $\frac{1}{12}$ in. deep; drive a piece of brass wire tightly into the holes, and allow the wire to project sufficiently to allow a piece of thin paper between the iron and the table when the iron is standing upon it; this is to prevent the armature adhering to the magnet from residuary magnetism, which always exists more or less. The measurements are—

No. 1 size iron ¾ in.,	*d* to *e* ⅝ in.,	*a* to *b* 1¼ in.
No. 2 „	$\frac{5}{16}$ in., „	¾ in., „	1⅝ in.
No. 3 „	$\frac{7}{16}$ in., „	¾ in., „	1½ in.

The Bobbins or Coils.—These are made by bending thin sheet copper round the part *a b* of the magnet; the edges at *a* (Fig. 42) must not quite meet. The thickness of this copper must be such that 4 pieces just equal in thickness the edge of a new threepenny-piece (this is rather an original gauge, but then all

can get at the thickness this way). The hole in the brass end *b* must be just large enough to push on firmly over the copper when on the iron; they must

FIG. 42.



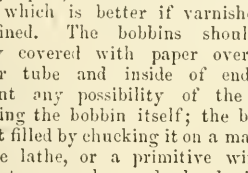
then be set true, and soldered on. The brass for the ends may be about as thick as a sixpence; a $\frac{1}{16}$-in. hole must be drilled at *c*, close to the copper. The other measurements are as follows:—

No. 1, diameter	$\frac{3}{8}$ in.,	length over all	$1\frac{1}{2}$ in.
No. 2, „	$\frac{7}{16}$ in.,	„	$1\frac{3}{4}$ in.
No. 3, „	1 in.,	„	$1\frac{3}{8}$ in.

The brass ends should be neatly turned true, and lacquered.

To fill the Bobbins with Wire.—For this purpose, No. 28 wire should be used, which is better if varnished or paraffined. The bobbins should be neatly covered with paper over the copper tube and inside of ends, to prevent any possibility of the wire touching the bobbin itself; the bobbin is best filled by chucking it on a mandrel in the lathe, or a primitive winding apparatus may be made by boring a hole through the sides of a small box, fit a wire crank and wooden axle to this, and push the bobbin on the projecting end—thus (Fig. 43): *a*, crank; *b*, box;

FIG. 43.



c, bobbin; *d*, axle. The box may be loaded to keep it steady; on any account do not attempt to wind the wire on by hand—the bobbin must revolve. Leave about $1\frac{1}{2}$ in. of wire projecting outside the hole *d*, in end of bobbin, and wind the wire on carefully and quite evenly, the number of layers being respectively 6, 8, and 10; the last layer must finish at the same end as the first began, and is best fastened off by a silk or thread binding, leaving about a 3-in. piece projecting. Both bobbins must be wound in the same direction, turning the crank from you, and commencing at the end nearest the box. The bobbins must now be firmly pushed on the part *a b* of the magnet, and the two pieces of wire projecting through the holes *c* soldered together.

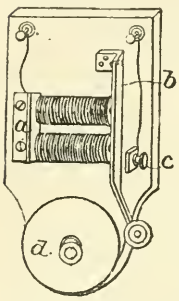
To put the Bell together.—First screw on the bell. This should be supported underneath by a piece of $\frac{1}{4}$-in. iron tube, long enough to keep the edge of the bell $\frac{3}{8}$ to $\frac{5}{8}$ in. above the backboard. Cut off the hammer-rod, so that when the head is on it will come nearly as low as the bell screw, and in a line with it. Make a hole in the backboard, and drive the armature post in tightly—it must be driven in so far that when the magnet is laid upon the backboard, the centre of the magnet iron and the armature are the same height. Place the magnet so that when the armature is pressed against it, the hammer-head all but touches the bell; screw it into its place by a wooden bridge across the screw passing between the bobbins. By afterwards easing this screw, any little adjustment can be made. The armature spring should tend to throw the hammer-head about $\frac{5}{8}$ in. from the bell. The contact-post should be so placed that when the armature touches the magnet, there is a slight space between the platinum point on the screw and the platinum on the spring. In putting in the posts, a piece of copper wire must be driven in with them to attach the wire to. One post can be moved round a little either way to alter the tension of the spring; the screw in the other post can be turned in or out, to just allow the proper break to take place. By screwing it in and out, the ear will soon judge where the bell rings best. (Volk.)

Examples.—It will doubtless be of considerable assistance to many amateurs to have a few examples illustrated and explained.

(1) Trembling Bell.—Make an electro-

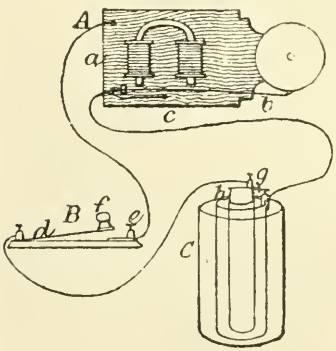
magnet, either out of $\frac{3}{8}$-in. iron bent round, or a piece of iron bent at a right angle, into which 2 cores can be screwed as at *a*, Fig. 44. On each of these cores wind 2 oz. 26 silk-covered wire; you may wind directly on to the iron, or make a bobbin; if you wind on to the iron, first cover each core with paraffin paper. The armature *b* is mounted on a spring containing the hammer at the other end. The spring is continued apart from the armature to a platinum-pointed screw *c*; this enables you to adjust the armature to a very great nicety. Lines show the connection of wires from binding-screws to electro-magnet. Of course, these wires go underneath the board. The bell *d* is suspended on a brass or iron post, with a thumb-nut on the top, screwing down on to the bell; 2 good Leclanché cells would work this bell well.

FIG. 44.



(2) A (Fig. 45) is the bell. This

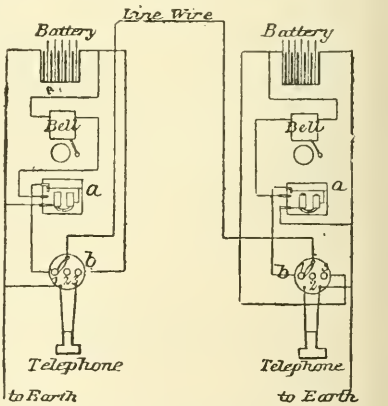
FIG. 45.



consists of an electro-magnet *a*, with a vibrating armature *b*; *c* is a brass spring tipped with platinum, which keeps the circuit closed so long as the bell is not ringing. The wires are connected to the push B, and battery C. Thus, when the push B is pressed down, the circuit is closed, the iron core in electro-magnet is magnetized, and pulls the iron armature on *b* close up, thus causing the knob to strike the bell, and at the same time breaking the circuit by leaving the platinum tip on *c*. The push B consists of a thin brass spring *d* and a binding-screw *e*, with a brass plate connected to it going immediately under the wooden knob *f*. The cell C is a Leclanché, with the carbon rod *g* in porous jar, well packed with an equal quantity of coke and lamp-black, oxide of manganese, and the zinc cylinder *h*. The lines show how the wires are to be connected up.

(3) Connecting Bells and Telephones by one Wire.—Use a relay, as shown in Fig. 46 at *a*. The switch *b* has 3 knobs,

FIG. 46.

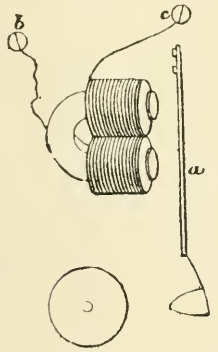


Nos. 1, 2, 3 The handles of both switches must be turned on No. 1 when not in use, awaiting calls, both on No. 2 for telephonic messages, and either on No. 3 for ringing bell to call attention at the other end. It would be better to have the bell single stroke (the connections make the difference), and the relay

will make it continuous. Make the relay of small size, and to fit in at the back of the switch. The action of the relay is thus:—When handle is turned on No. 3 right-hand switch, a current of electricity is sent through wire to the other end, through No. 1 knob to electro-magnet in relay, which draws down the spring until it touches the other wire, which sends a current through the battery, and strikes the bell. The other connections will explain themselves.

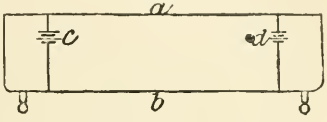
(4) Single-stroke Bell.—Fig. 47 explains its construction. Instead of having a contact-breaker fixed at *a*, the circuit only goes through the magnet, thus only ringing when the button is pressed. *b* and *c* are connected with the battery.

FIG. 47.



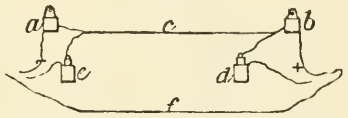
(5) It is possible to ring 2 bells with only 1 wire by having 2 series of cells: but this involves much more expense and trouble than laying a double wire and one series of cells. You can work with 1 wire if you allow both bells to ring at the same time, and have a battery at each end, or you can so arrange the batteries and bells as to throw battery of one end in circuit with the bell of the other end, and so on, as in Fig. 48, where *a* represents the gas-pipe; *b*, line wire joined up with bells in circuit; *c* and *d*, 2 wires going through cells and on to pushes in connection with line wire. Thus, when either of the pushes is closed down, the battery and distant bell are in circuit, and vice versâ.

FIG. 48.



(6) The subjoined arrangement (Fig. 49) is a simple way of effecting the same object as the preceding. Let *a b* be bells at shop and house respectively; connect the line wire *c* with a binding-screw of each bell, as shown. Have a battery at shop and another at house, *d* and *e*; connect line-wire also with one pole of each battery; connect the remaining binding-screw of each bell with

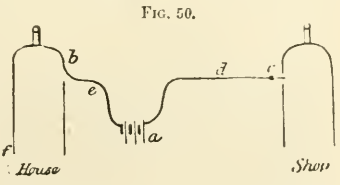
FIG. 49.



a metallic plate; connect the remaining poles of batteries, each with a metallic plate. Instead of the ordinary "push," arrange metallic springs at shop and house, permanently connected with gas-pipe *f*, and so placed that when at rest they are in contact with the plates.

(7) Fig. 50 shows another solution of the same difficulty. The battery *a* is

FIG. 50.

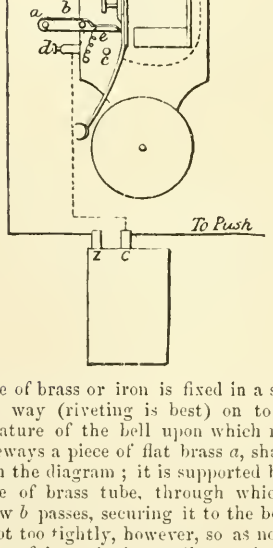


placed in the house. At *b* and *c* are 2 small levers, which can be moved so as to put the line wire *d*, and the short wire *e*, which constitute the poles of the battery, in connection with the earth in 2 sets of ways. The figure shows the connection in case it is wished to ring

the house bell from the shop. Before leaving the house, bring the lever *b* in connection with the wire which traverses the electro-magnet of the house bell; thus *c* is brought into connection with the earth at *f*. Whenever, then, in the shop, you press down the lever *c*, you complete the circuit, and the house bell rings. Before leaving the shop, raise the lever *c* so as to bring the shop bell into the circuit, and when returning to the house you can complete the circuit, and cause the shop bell to ring every time you press down the lever *b*.

(8) Continuous-ringing Bell.—This is more complicated than the single-stroke, as will be seen by Fig. 51. A small

FIG. 51.



piece of brass or iron is fixed in a suitable way (riveting is best) on to the armature of the bell upon which rests edgeways a piece of flat brass *a*, shaped as in the diagram; it is supported by a piece of brass tube, through which a screw *b* passes, securing it to the board—not too tightly, however, so as not to allow of its swinging easily; a piece of brass rod or stout wire *c* is driven into the base-board in such a way that when *a* is drawn down by the spring *e*, a good contact is formed between *a* and *c*. A wire is taken from *c* to one binding-screw of the bell, and a wire is taken from the brass tube which supports *a* to another separate binding-screw *d*. The dotted lines represent wires as well as the other lines; the dotted lines also represent the direction of the current for the continuous action, using the same wire to the zinc element. The current passes from the zinc to the contact-screw, through the coils to *c*, across *a*, down *b*, and out through the binding-screw *d* to the carbon element. The bell is stopped by pulling a cord attached to *a*, which breaks the contact, and which, if pulled hard enough, forces the armature towards the magnet by rubbing against the piece in the armature (which must be made in the shape of the diagram). When it gets above the piece in the armature, the armature springs back, and *a* rests on the piece of brass again, ready for another time.

(9) Method of producing continuous ringing from an ordinary Electric Bell.—The method works well, is inexpensive, and any one with ordinary intelligence could make and fix one for himself. Of course, the bell must have a contact breaker. In Fig. 52, *a* is the bell; *b*, hammer, in the centre of which is screwed or soldered a piece of metal projecting outwards $\frac{1}{2}$ in. The head of hammer is flat, circular, with a hole in centre; *c*, piece of brass hung loosely on the screw, to which wire is attached, leading to bell as shown; *d*, screw and wire attached, leading to battery. On the bell being rung, the oblong piece of brass *c* is liberated, falling on to *d*, making a new circuit, producing continuous ringing until *c* is lifted up. (J. W. Fisher.)

(10) Connecting Telephones and Bells.—In Fig. 53, *d* is a piece of brass shaped like the shafts of a cart (only the telephone takes the place of the horse), secured to the base-board by a short piece of steel spring. The telephone, by its weight, brings *b* into contact with *c*, thereby breaking communication with the speaking instrument, and bringing the bell *e* into readiness for receiving a signal. Directly the telephone is re-

FIG. 52.

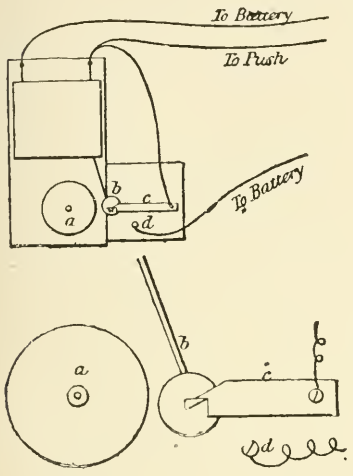
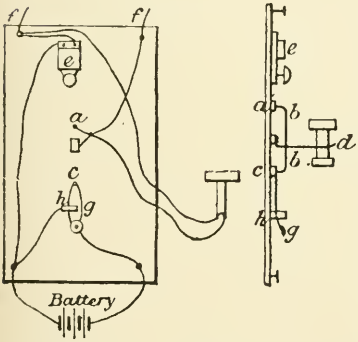


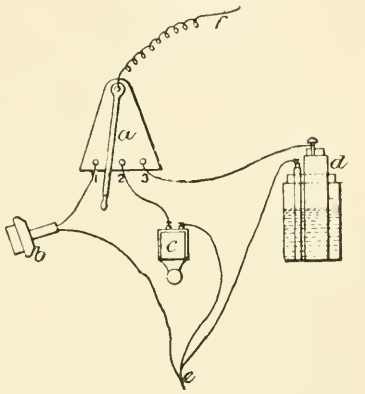
FIG. 53.



moved, *d* springs up, making contact at *b a*, so bringing the telephone into connection with the line wire *f*. As shown in the sketch, the bell is ready to receive a signal from the distant station, but by pressing down the spring *g* (similar to the key used for the Morse telegraph), you cut off connection at *h*, and bring your own battery into action, thereby ringing the bells. The board should be suspended against a wall.

(11) Another plan.—Make connections like Fig. 54 at both ends: *a*, switch; *b*, telephone; *c*, bell; *d*, battery; *e*, earth (water or gas-pipe will

FIG. 54.

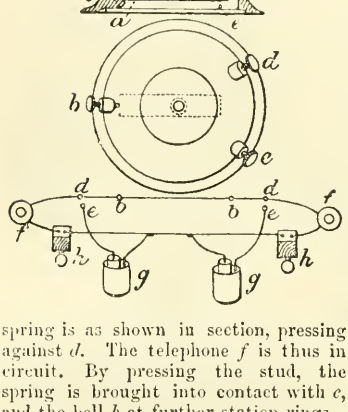


do); *f*, line-wire. The switch is made of a piece of wood with 3 studs at bottom, connected with the wires as shown. A strip of brass is made to slide over them so as to make contact, and communicate with line wire. When not in use, the handle must be in contact with the centre stud at both ends, to call attention at the other station. Put the switch to No. 3 stud, which will ring his bell for a few seconds, and put your switch back to stud 2. The other station now must just do the same to let you know that he is there, and as soon as the bell stops ringing, move the switch to stud 1 to connect telephones. The other station must move his switch as soon as he has rung reply to your call. You can now go on with your speaking, and as soon as finished move switch to stud 2 at both ends.

(12) Another plan.—The push in Fig. 55 is of rather peculiar construction. A spring *a* is connected, through a binding-screw *b*, with the line-wire *c*, and is fixed so that the free end plays between two contact-pieces *d* and *e*, the former of which is connected with the telephone *f*, the latter with one pole of the

Leclanché cell *g*. The other pole of the battery is connected to the return wire, or, in the case of there being no return wire, to earth. The normal position of

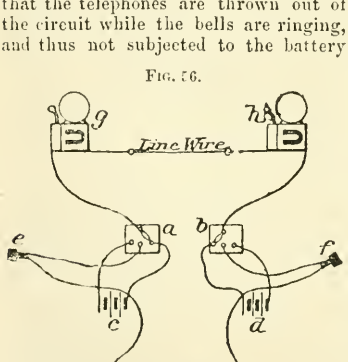
FIG. 55.



spring is as shown in section, pressing against *d*. The telephone *f* is thus in circuit. By pressing the stud, the spring is brought into contact with *c*, and the bell *h* at further station rings.

(13) Another plan.—The following method of connecting bells and telephones with one wire has the advantage that the telephones are thrown out of the circuit while the bells are ringing, and thus not subjected to the battery

FIG. 56.

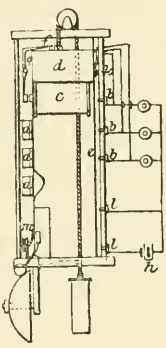


current, wherefore perhaps it is to be preferred. In Fig. 56, *a b* are 2 switch arrangements, having a movable arm fixed to the top button, capable of sliding over the lower 3, and making contact with either. *c* and *d* are the batteries, *e* and *f* the telephones, and *g* and *h* the bells. In the diagram, the switches are shown in the position in which they are always left after using. Then, by turning either of them on to the end button, both bells ring, thus letting the ringers know that the circuit is complete. The switch is then moved back for the answer. When that has been received, both switches are moved to the middle button, which brings the telephones into circuit, and conversation may be carried on. It is necessary to remember to move the switches back after the conversation is finished. This arrangement is used over 300 yd. of uninsulated copper wire, which is carried over the roofs of several houses and across 3 streets without any insulation whatever, and the gas-pipe is used for the return circuit. It employs 3 Leclanché cells of 1 pint capacity; 2 were not powerful enough. This has been in use for several weeks, and the weather does not seem to have had any bad effect on bells or telephones. A wrinkle connected with the telephone is, that the strength of the magnet makes more difference than some might suppose. A pair which were working miserably, when taken to pieces, and the magnets re-magnetized, work splendidly. Iron cores don't make any perceptible difference for ordinary purposes, and $\frac{3}{4}$ oz. of wire works perhaps rather better than $\frac{1}{4}$ oz., but there is very little difference.

(14) In Brailsford's arrangement, Fig. 57, 1 magnet suffices to ring the bell and to indicate the place from which the signal has been sent. The electro-magnet is fixed to a block capable of sliding up and down in a vertical tubular case. When the block is at the top of the case, it is held up by a catch; the catch has an arm extending from it, which carries a soft iron armature just in front of the poles of the magnet, in order that when the armature is attracted it shall release the catch and allow the block to drop

to the bottom of the case. As the block so descends, the poles of the magnet are carried past a series of other soft iron armatures, situated at distances apart one below the other. If a current is passed through the coils of the magnet when it is opposite to any of these armatures, the armature is attracted, and moves a distance towards the magnet, and in doing so shifts a signal or indicator *a* connected to it, and so indicates which armature has been moved. When the block reaches the bottom of the case, the poles of the magnet come opposite another armature, by means of which the bell is to be rung, and an electric current being then caused to pass through the coils of the magnet, the bell is rung, and (in the event of a continuous signal being desired) does not cease to ring until the block is lifted up again to the top of the case. In some instances, the falling of the block might be made to complete a circuit through the magnet coils of a separate bell apparatus, instead of the magnet on the block being made to ring the bell.

FIG. 57.



From each room an insulated wire is led to the part of a building in which the apparatus is placed. In each room is, as usual, a contact apparatus by which such wire can be coupled to a main wire from one pole of a battery. The ends of all the wires are led into the top of the casing of the apparatus. When the block is at the top of the case, a metallic contact mechanism carried by the block is in contact with each of the wires; the contact is also coupled to one end of the coils of the electro-magnet; this end of the coils of the magnet is also coupled to a metallic contact spring, which, when the block falls, comes in succession against a series of metallic contact plates *b*, fixed at distances apart one below the other. There are as many contact plates as wires from the several rooms, and each plate is coupled to one wire. The other end of the coil of the magnet is coupled to another contact spring carried by the block, and this spring always rests against a metallic rod which extends from top to bottom of the case, and is coupled to the other pole of the battery. In this way, whenever one of the wires leading from any room is, by the pushing in of a press-button or other contact apparatus, coupled up with the main wire from the battery, a current will pass through the coils of the magnet; the magnet will attract the armature attached to the catch, and will release the catch; the block will drop, and when the contact spring it carries passes over the contact plate, which is in connection with a branch of the same wire through which the current previously passed, the current again passes, the armature, which is then opposite to the poles of the magnet, is attracted, and the signal in connection with that armature is moved. The speed at which the block is allowed to descend can be controlled by suspending the block by a cord passed over a pulley, and having a counterbalance weight attached to it. The electro-magnet might be arranged to move in a circular course.

Alternately the armatures may be made to travel in front of the fixed electro-magnet, and operated by a hanging weight. The successive completion of the different circuits will be made as specified, the relative movements of the magnet to the indicative armature and to the bell being the same. In the figure, *c* is the electro-magnet, fixed to a carrier or block *d*, which slides up and down the tube *e*. The block and magnet are suspended by the notched rod *f*, held by the lever detent *g*, which is provided with a soft iron armature, and is thus attracted to the magnet when the circuit is completed, releasing the magnet and block, and allowing them to fall; *h* represents any suitable galvanic battery, with different room circuits and bell

pushes *i*. When the magnet reaches the bottom of the case, spring *k* is in contact with the stud *l*, the termination of a permanently closed circuit. The recovered magnetism of the electro-magnet will then operate, by the vibration in the usual way of the spring armature *m*, an ordinary electric bell, which will continue to give warning until the attendant raises the electro-magnet to its former position, thereby also tilting back any displaced indicator label.

General Hints.—(1) The amounts and sizes of silk-covered wire to be used for making coils for electric bells are as follows, the number of inches indicating the diameters of the respective gongs:—For a 2-in. gong, 8 yd. of No. 26; 2½-in., 9 yd. No. 26; 3-in., 10 yd. No. 26; 3½-in., 10 yd. No. 26; 4-in., 11 yd. No. 24; 5-in., 12 yd. No. 22; 6-in., 13 yd. No. 20. (2) The bells after being turned and polished receive an electro deposit of nickel or silver, or they may be warmed and lacquered with gold-lacquer in the lathe; screws and other brass fittings are done the same way. (3) It is immaterial whether the bell support be of iron or brass. (4) For winding the bobbins quickly and neatly, have a steel spindle, about ¼ in. diameter, fixed in 2 bearings on uprights on a stand. Cut 2 pieces of stout brass tube (¾-in. common tube) each 1 in. long; turn each down taper to one end, and put a set-screw in each; then slide them over the ¼-in. spindle, so that their thin ends are nearest together. Reels with holes of many different sizes can thus easily be fixed true and wound very easily, either in the lathe, or by hand by means of a small crank.

(5) A difficulty with the Leclanché battery is that the sal-ammoniac solution rises by capillarity, and attacks the leaden taps, brass binding-screws, and wires. The following suggestions relate to batteries:—(*a*) Take your battery to pieces, well wash in hot water to remove the chloride of lead, dry, and give a good coating of Brunswick-black; after setting up, give another, so as to thoroughly protect the leaden caps. (*b*) Try a few drops of sweet-oil on the surface of solution, to prevent verdigris on binding-screws. Try a chloride of zinc battery instead of a Leclanché. A 4-cell bichromate form battery, with sal-ammoniac solution, can be used for bells with great success and no trouble. (*c*) Avoid brass-work on Leclanché cells; prefer lead connections covered with Brunswick-black or black Japan varnish, which prevents salts from creeping up and destroying the connections. Prefer wires (blacked over) to lead outside battery-box, having the terminals for connecting the cells outside the box. A Leclanché set of 6 cells will work for nearly 3 years on a bell circuit by simply refilling with water occasionally. (*d*) Take out the carbons, well soak the heads in melted paraffin for say 2 in. down, then, by reheating carbons, drive back the paraffin for sufficient space for binding-screws to take on. If you have time, you might electrotype the heads and solder the binders to this. But in any case, you will find the paraffin wax prevent the creeping action of the excitant. (*e*) When you put the zinc rod into the solution (which should be only half up the outer jar), see that it is well amalgamated, and do not let it touch the porous cell. (*f*) To prevent the salt and water creeping up, grease the upper portions of the carbon, zinc, and jars; to check evaporation, place your cells in a wooden case, and screw on the front so as to be air-tight. When so fitted, if the insulation is good, Leclanché batteries of the best make will work well without any attention for several years; one working house-bells has been in daily use for 9½ years, during which time it has been filled up with cold water 5 times, and been recharged once. Neatsfoot-oil is the best kind of grease for this purpose. (*g*) Get new carbons, made out of gas-retort "scurfing," as it is called, then prepare the ends that are out of the solution, thus:—Thoroughly scrape the top of the carbon, fit nicely on a piece of sheet platinum like an inverted V, fix the binding-screw on tightly, and then coat the carbon and connection (previously well warming both) with

shellac varnish or Brunswick-black. As to the zinc connection, do not use a binding-screw at all near the cell, drill the zinc, and insert a tinned iron wire, or twist it round the rod and well solder it, then warm, as you do the carbon, and coat with the Brunswick-black. Do all connections with binding-screws fixed to a frame, say 10 or 12 in. away from the cells, where the fumes cannot well reach them. Do not wet the carbons or zincs when putting the solution in—*i.e.* that portion which is not intended to be in—and do not fill the jars above $\frac{3}{3}$ full.

Carbons.—The rods first used for the electric light were of wood charcoal, quenched in water or mercury; they burnt with brilliancy and regularity, but too rapidly. Next, the carbon which is deposited in gas-retorts was employed; its chief faults are found to be want of homogeneity and purity, causing variations in brilliancy; liability to split; and hardness, entailing considerable cost for cutting it into "pencils" of the required size. With the sudden impetus given to electric lighting, much ingenuity has been devoted to the production of a more suitable carbon for this purpose. In some instances this has been attempted by purifying gas-retort carbon. The first plan of this kind was as follows:—The retort carbon is fused with caustic potash or soda, and the carbon rods are digested in this bath at a red heat for 15 minutes. In this way, the silica present is converted into a soluble silicate; the rods are then washed in boiling water, and are submitted for several hours to the action of chlorine at red heat, to change the earthy matters into volatile chlorides. These rods give a regular light, but the purification is costly and inefficient. From a number of experiments on retort carbons impregnated with different salts, it seems that potash and soda double the length of the voltaic arc, render it more silent, combine with the silica, and eliminate it from the carbons during the action of the current; they also augment the light in the proportion of 1·25 to 1. Lime, magnesia, and strontia increase the light as 1·40 is to 1; iron and antimony, as 1·60 or 1·70; boracic acid is said to lengthen the durability of the carbons by coating them with a vitreous layer, but it does not increase the light.

On the other hand, experiments have been made with a view to manufacturing a carbon from other sources. In one instance, it was endeavoured to imitate the process of formation of retort carbon with pure materials. Tars resulting from true distillation, therefore free from all non-volatile impurities, were decomposed in a tube of refractory earth in a furnace, and yielded plates of carbon which, when cut into "pencils," gave a light that was steadier, whiter, and 25 per cent. more powerful than that obtained with ordinary carbons. The hardness of the material, however, entailed great cost for cutting, and caused much waste. Another plan consisted in mixing 2 parts of pulverized retort carbon, 2 of pulverized wood charcoal or coke, and 1 of tar, rendering the mass a stiff paste, and subjecting it to great pressure. The moulded pieces were covered with a coating of syrup of sugar, placed beside each other in a vessel of retort carbon, and submitted to great heat for 20 or 30 hours. At an early date, a mixture of pulverized coke and sugar was proposed. To powdered coke a small quantity of syrup was added, and the compound was pugged, moulded, and strongly pressed. Next it was heated moderately, thrust into a concentrated solution of sugar, and finally heated to whiteness. Curmer's carbon consists of lampblack, benzine, and oil of turpentine, calcined together, and moulded into cylinders of porous carbon, which is soaked with resins or saccharine matters, and again calcined. The objections to this are the high price of lampblack, and the difficulty of managing it. Peyret's carbon is prepared by soaking pieces of elder-tree pith, or other porous materials, in liquefied sugar, and decomposing the sugar by heat. By repeating this process, a dense carbon is obtained; it is then submitted to a

current of carbon bisulphide vapour. In Archereau's carbon, the addition of magnesia makes the light steadier and increases its power. Carré adopts the following mixture:—15 parts coke powder, 5 of calcined lampblack, and 7 to 8 of a syrup (composed of 30 parts cane-sugar and 12 gum). The whole is thoroughly triturated, and receives an addition of 1 to 3 parts water to compensate for that lost by evaporation. The paste is pressed, and passed through a draw-plate. The carbons are next arranged in horizontal layers in a crucible, the lowest tier lying on a bed of coke-dust, and the upper ones separated by paper to prevent adherence. Between the top and the cover of the crucible is placed a stratum of coal-dust; and upon the joint of the cover is spread siliceous sand. In this position, the carbons are strongly heated, and are then placed for 2 or 3 hours in a concentrated boiling syrup of cane-sugar or caramel, 2 or 3 intervals of cooling being admitted in order that atmospheric pressure may force the syrup into all the pores of the carbons. These are then allowed to drain by opening a tap in the bottom of the vessel; after this, they are well washed with boiling water, to remove the sugar adhering to their surface. When dry, they are subjected to a second heating, and are passed through a repetition of the process till the requisite density is obtained. In many respects they resemble retort carbons, but are harder, more tenacious, and better conductors.

Upon the introduction of foreign substances into the carbon rods, a number of experiments have been made. The materials chosen have been lime phosphate, lime borate, lime silicate, calcium chloride, magnesia phosphate, magnesia borate, magnesia, alumina silicate, and pure precipitated silica, with the following observed results:—

Lime phosphate is completely decomposed, reduced calcium goes to the negative carbon, and in contact with the air it burns with a reddish flame. Lime and phosphoric acid are abundantly diffused in fumes. The light, as measured by a photometer, is double that produced by similar-sized rods of retort carbon.

Lime borate and silicate, and calcium chloride are all decomposed; the boracic and silicic acids are volatilized, and escape electric action. The light does not equal that from lime phosphate.

Magnesia salts are decomposed; the magnesium burns with a white flame, while the acids are vaporized. The light is less than from lime salts.

Alumina silicate and alumina require a very strong current to effect their decomposition, and burn with a blue flame of small illuminating power.

Silica melts and volatilizes without undergoing decomposition.

Gaudoin has proposed 2 distinct methods of preparing carbon for electric rods. According to the first, he decomposes, by heat, organic matters capable of yielding pure carbon after decomposition, *e.g.* pitches, fats, &c. The decomposition is effected in closed retorts, or in graphite crucibles, at bright red heat. In the bottoms of the latter, are provided a tube for the liberation of volatile matters, and a second tube for feeding purposes. The gaseous products of decomposition are led into a condensing chamber, for recovery and utilization. The more or less compact carbon remaining in the retort is finely pulverized, and with it are mixed certain proportions of lampblack, and of the carbides of hydrogen previously produced by the decomposition process. These, being quite free from iron, are much superior to commercial hydrocarbons. The draw-plate or moulding apparatus employed by Gaudoin differs from that commonly used in the following important particulars:—The carbon is made to issue horizontally, at a descending angle of about 50°, guided by tubes, and supported so that the mould can be emptied without interruption and the carbon does not break under its own weight. Gaudoin's second plan is to take dried wood, shaped in the form of the rod, and to carbonize and soak it in carbonaceous liquids. The wood is subjected to a

slow distillation process, in order to drive off the volatile matters; then washed in acids or alkalies, to remove impurities; and finally desiccated in a reducing atmosphere at very high temperature. The pores of the wood are closed by submitting it to the action of carbon chloride and various hydrocarbons under heat. This process promises to afford carbons which will burn at a slow rate, and give a steady light.

The advantage derived from closing the pores of carbons has been further attested by the success of the Sawyer and Mann rods, which are prepared in the following manner:—The carbon rod is immersed in olive-oil until it has become thoroughly saturated; while in this condition, it is included in a powerful electric current, the effect of which is to carbonize the oil in the pores and on the surface. Rods thus prepared are extremely hard, of steel grey colour on the surface, and give very constant light.

Bad carbons are undoubtedly rendered more uniform conductors by covering them with a coating of metal. A great increase of light is also secured by a slight coating of metallic bismuth, or by saturating with a solution of bismuth nitrate. It has been proposed to attain the same end by incorporating powdered copper or iron with the carbon; also by inserting a wire core in the rod, and by winding a thin strip of metal around it.

Jacquelain has pointed out that carbon for the electric light should be purer than that obtained by calcining wood; and, if not free from hydrogen, should at any rate contain no mineral impurities. He gives 3 methods for accomplishing this result: (1) By the action of a jet of dry chlorine gas directed on the carbon, raised to a light red heat; (2) by the action of potash and caustic soda in fusion; and (3) by the action of hydrofluoric acid on the finished carbons. Jacquelain has prepared carbons by all 3 methods, and has summed up in a table the photometric results of his experiments. He comes to the conclusion that the luminous power and regularity of the voltaic arc increase in direct ratio to the density, hardness, and purity of the carbons. He remarks, incidentally, that the natural graphitoïd of Siberia possesses the singular and unexpected property of acquiring by purification a luminous capacity double that which it has in the natural state, and which exceeds by $\frac{1}{6}$ that of pure artificial carbons. In passing dry chlorine gas over pulverized coal or coke heated to bright redness, all the silica, alumina, and magnesia, as well as alkalies and metallic oxides, are converted into volatile chlorides and expelled; even the hydrogen is driven off as hydrochloric acid. The easiest method of carrying out the process on a large scale is to allow the dry chlorine gas to act upon gas carbon—from the retorts—cut into thin prisms, for 30 hours, and then raise the temperature to a bright white heat. This makes the carbon porous; in order to convert into a dense, heavy carbon, which is a good conductor and not easily combustible, the vapours of heavy tar-oils are passed slowly over the pieces of glowing carbon, when a deposition of carbon will take place within the pores of the coke. If the carbon rods are treated with fused sodic hydrate (caustic soda), the silica and alumina will be dissolved as soda silicate and aluminate, and can be removed by washing with hot water. Oxide of iron and other constituents of the ash are removed with hydrochloric acid followed by pure water. The simplest process recommended by Jacquelain, is to leave the carbons for 2 or 3 days in dilute hydrofluoric acid, at ordinary temperature, then wash well, and expose for a few hours to a slow current of tar vapours at a high temperature. (*Comptes Rendus.*)

With direct currents, the positive carbon burns away at double the rate of the negative, owing to the much higher temperature which it undergoes, amounting to whiteness as compared with dull redness. With alternating currents, the carbons are consumed equally. This consumption is also completely avoided by producing the voltaic arc *in vacuo*.

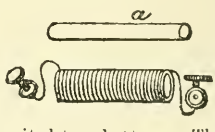
Carbons of $\frac{1}{2}$ in. diameter burned with a current of 75 ampères give a light equal to 400 gas-burners, each using 500 cub. ft. per hour. The weight of carbon burned is 0·79 oz. per hour, requiring 2·11 oz. or 1·57 cub. ft. of oxygen. A $\frac{1}{4}$-in. crater in the positive carbon will necessitate a deduction of 15 per cent., giving 1·32 cub. ft. of oxygen per hour employed in the formation of carbonic acid.

Varley has devised an electric lamp in which he uses fine filaments in a rope-like bundle as the poles of the arc. It is said that the space between the two points is so heavily charged with incandescent carbonaceous matter that the resistance is considerably reduced, and the "light" is of much greater area, for the luminosity comes from the arc itself and not so much from the carbons, which no longer present the cup and cone formation, although possibly the filaments individually preserve the distinctive shape. An advantage is that the carbons are flexible, can be wound on a reel, and be paye1 out by means of clockwork. The carbons are made of pieces of rope soaked in paraffin or ozokerit, and carbonized in a crucible kept constantly filled with a hydrocarbon atmosphere.

Coils, Induction.—An electrified wire is capable of exciting a current in another wire placed near it, but not in contact, and such a current is termed an induced current. Induced currents generally have a very high electromotive force, and are capable of sparking across far greater spaces than can be accomplished by ordinary battery currents. An induction coil consists of a cylindrical bobbin with an iron core, surrounded first by a primary coil of stout wire, and then by a secondary coil of very fine wire, carefully insulated between the different parts. The primary coil is joined to the terminals of some Bunsen or Grove cells, and includes an interruptor (contact breaker) and a commutator. The object of the former is to repeatedly and rapidly make and break the primary circuit. The primary coil, destined to carry strong currents, and produce a powerful magnetic field at the centre, is made in few turns, so as to lessen resistance and avoid self-induction of the primary current. The iron core, whose value depends upon its great co-efficient of magnetic induction, is best made of a bundle of fine wires to avoid induction currents. The secondary coil is made in many turns that the co-efficient of mutual induction may be large, its increased resistance being immaterial in the presence of such great electro-motive force. With these general explanations, the construction of induction coils may be entered upon, the information being mainly condensed from Dyer's practical little book.

Primary Coil.—Prepare a paper tube, about 4 in. long and $\frac{3}{4}$ in. diameter, and wind on it 2 or 3 layers of copper wire covered with cotton, and of the size of ordinary bell wire. A binding-screw is attached to each end of the wire, as shown in Fig. 58, by which means it

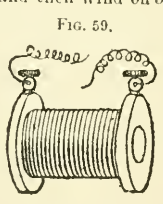
FIG. 58.



can be united to a battery. The paper tube upon which the wire is wound is filled up with a bundle of iron wire *a*.

Secondary Coil.—Prepare a second paper tube of similar length to that in the centre of the primary coil, but large enough in diameter to slide over it. Fit 2 discs of wood on the ends of this tube, and then wind on 5 or 6 layers of cotton-covered copper wire about the size of stout packthread, and attach binding-screws to its beginning and end (Fig. 59). If the primary coil be attached to a battery, and contact be broken rapidly, distinct shocks may be felt from the induction coil. Thus are constructed the coils of electro-magnetic

FIG. 59.



machines for medical and experimental purposes. But such are not intensity coils, for their mode of construction involves the loss of nearly all the electrical current excited in the wires of which they are composed.

Contact-breakers, or Interruptors.—Fig. 60 represents the apparatus devised by Dr. Ritchie as a mode of obtaining rotary motion by the temporary magnetization of an iron bar, which is extensively employed as a contact-breaker. It consists of a circular wooden disc placed between the poles of a horse-shoe magnet, having a deep channel turned in it so as to form a cup. This cup is divided into 2 parts by a wooden bridge, the ends of which come opposite to the poles of the magnet. A brass pillar rises up the centre of the bridge, supporting on its top an iron bar wound with insulated wire, the ends of which come down into the cup, and are of such a length, that when the iron bar is rotated, they will just pass over the bridge without touching it. This bar, or electro-magnet, as it really is, has a pointed pin projecting from its underside, which fits into the brass pillar, allowing the bar to rotate with very little impediment from friction. The 2 semi-cups are filled with mercury, which will stand up above the top of the bridge, the latter thus causing a sort of trough between them.

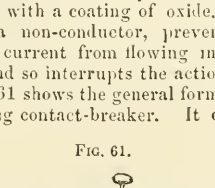
Fig. 60.

The 2 wires from the electrodes of a battery are put into the mercury, and the rotating bar is moved round so that it may stand across instead of in the line of the bridge. As soon as this is done, the wires from the iron bar will touch the mercury, and the battery current will circulate round the bar and convert it into an electro-magnet. The N. and S. poles of the horse-shoe magnet will attract dissimilar poles, produced in the iron bar by the action of the battery current, and draw them round until they are opposite the 2 poles of the horse-shoe magnet. This operation will also carry the wires out of the mercury, communication with the battery will be interrupted, and consequently the electro-magnet will lose all its properties. But the impetus it acquired by its partial rotation will carry it a little beyond the line of the bridge, and this will bring the points of the wires again into the mercury, though not in the same semi-cups as before; the battery current therefore flows through the wire on the iron bar in the opposite direction, consequently the polarity acquired by the bar is opposite to that which it had before. The end of the electro-magnetized bar that is now N. is thus near the N. pole of the horse-shoe magnet, and these 2 mutually repel each other, and by this force the rotating bar is driven to a position at right angles to the bridge, and where its N. can be attracted by the S. of the horse-shoe magnet. By this alternative magnetization and demagnetization, an attractive and repulsive action is obtained, by means of which a rapid rotation is produced, and a contact made and broken twice in each revolution.

Though convenient for some purposes, this is not suitable for large batteries or coils. Every time the wires leave the mercury, a vivid spark occurs, and the surface of the mercury soon becomes covered with a coating of oxide. This being a non-conductor, prevents the battery current from flowing into the wire, and so interrupts the action.

Fig. 61 shows the general form of the vibrating contact-breaker. It consists

Fig. 61.



of a base-board having an outer brass pillar, a central brass pillar, and an electro-magnet. The electro-magnet is

fixed to the board with its poles upwards, and of the ends of the wire wound on it, one is left open, so that the battery may be connected with it, and the other passes under the board to the base of the central pillar. The outer pillar, at its upper part, holds the end of a metallic spring which passes through the ring of the central pillar to the poles of the electro-magnet. Here the end of the spring is armed with an iron plate or clapper, which should stand, when the spring is at rest, about $\frac{1}{10}$ in. above the poles of the electro-magnet. A screw passes through the ring at the top of the central pillar, and comes just into contact with the spring. The spring at this point and at the end of the screw is of platinum. When one electrode of a battery is attached to the open end of the wire of the electro-magnet and the other to the outer brass pillar, the circuit is complete. If the anode of the battery be connected with the electro-magnet, the current will enter there, circulate round it, communicate magnetic properties to it, pass under the board to the central pillar, rise up here to the ring, descend through the screw to the spring, and thence by the outer pillar to the cathode of the battery. The electro-magnet will now attract the iron clapper at the end of the spring down to itself, and by this means a separation takes place between the end of the screw and the spring, and the battery circuit is interrupted. The electro-magnet can no longer hold the clapper down; the spring thus liberated rises to the position it formerly occupied, and again comes into contact with the end of the screw that passes through the ring. As soon as this takes place, the current again flows, and the electro-magnet draws down the clapper. Thus a rapid vibration is kept up, every oscillation of the spring being associated with making and breaking contact with the battery. When applied to intensity coils, it is usual to employ the iron bundle forming the core of the coil as the electro-magnet, and to place the vibrating spring vertical instead of horizontal.

Foucault's contact-breaker consists of a brass arm, which dips a platinum wire into a cup of mercury, whence it draws the point out, so breaking circuit, in consequence of its other end being attracted towards the core of the coil whenever it is magnetized; the arm is drawn back by a spring when, on the breaking of the circuit, the core ceases to be a magnet.

A common contact-breaker on small coils is constructed of a piece of thin steel which makes contact with a platinum point, and which is drawn back by the attraction of the core on the passing of a current, and so makes and breaks circuit by vibrating to and fro like the hammer of an electric bell.

Coils, Intensity.—The parts of an intensity coil are: reel, primary coil, secondary coil, iron bundle or core, contact-breaker, condenser, pedestal or base, and commutator. The dimensions given may be considerably varied without impairing the efficiency of the apparatus.

Reel.—The reel consists of a hollow cylinder or tube, with a square or circular plate firmly fixed on each end. The cylinder is formed of paper, and the plates or reel-ends of guttapercha or ebonite. The reel-ends are flat, and not less than $\frac{3}{8}$ in. thick; if circular, a facet is made on the edge of each, so that when the reel is complete it may stand steadily on the pedestal. The hole through the centre of the reel-ends is turned perfectly true, so as to fit the outside of the cylinder; and a shoulder is left on the outer face sufficient to prevent the paper cylinder from being pushed through the ends when being fastened on. The reel-ends may be $4\frac{1}{2}$ in. in diameter if circular, or 4 in. by 4 in. if square. They can be glued to the paper cylinder. The cylinder is formed of cartridge-paper cut into a long strip, and when gummed or pasted on one side, wound round a rod $\frac{7}{8}$ in. diameter. When properly done, a firm tube, 7 in. long, 1 in. diameter, and about $\frac{1}{16}$ in. thick, is obtained. This is allowed to dry thoroughly, and the ends are cut at right angles to the axis. The ends

are firmly fastened to the cylinder; in order to effect this, the holes through the discs are slightly tapered, the larger dimensions being towards the shoulder. Before fixing the paper cylinder, a slightly conical plug is provided, fitting the inside of the cylinder. When the parts are ready and carefully coated with the glue, they are put together, and the conical plug is gradually pressed into the end of the cylinder, which will expand it a little, and force it into close contact with the sides of the hole in the disc; it remains in this position until the glue is thoroughly set, when the plug can be removed. The reel is provided with a hollow groove in the edges of the discs, if circular, to receive the pieces of catgut cord that are to fasten it to the base; if square, they can be fastened by screws; 2 holes are drilled through one end of the reel, to allow the primary wire to be passed through; these should be about $\frac{1}{8}$ in. diameter, and somewhat oblique in direction, so that the wire, where passed through the reel-end, may not be at right angles with the axis of the reel.

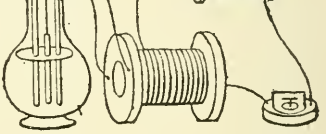
Primary Coil.—The primary coil consists of No. 16 cotton-covered copper wire, averaging about 18 yd. to the lb. One end of the wire is passed from the inside through one hole in the reel-end, so as to project 6 or 8 in., and the wire is then carefully wound over the cylinder up to the other end, and back again, so as to form 2 layers, one over the other. When completed, the remaining end of the wire is passed through the second hole in the reel-end. Before putting on the wire, fit a wooden or metallic rod inside the paper cylinder of the reel, or the cylinder is likely to be damaged by the force required to wind the wire round it. When the primary wire is on, it is varnished with 2 or 3 successive coats of shellac dissolved in spirits of wine, care being taken that one coat is thoroughly dry before another is put on. The first coat should be thin, so as to be readily absorbed by the covering of the wire and conveyed to the nether layer. When the varnish is dry and hard, the primary wire is covered with a strip of cartridge-paper passed 2 or 3 times over the wire, and fastened by gum or glue. This paper must be cut exactly to the width between the inside faces of the ends of the reel, and drawn tightly when put on, but not so tightly as to show on its surface the interstices between the rows of wire. This paper covering, when dry, is varnished to present a smooth cylindrical surface, having no space between it and the inside face of the reel ends. Shellac varnish forms a good insulator, but is not so effective as ordinary black rosin and beeswax. This preparation is rather more difficult to apply, but greatly superior to the varnish when done. The rosin is melted in an earthen vessel, and a small quantity of beeswax is added to it, the proportion to be determined by experiment, the use of the wax being to diminish the friability of the rosin without interfering with its hardness: usually about $\frac{1}{5}$ by weight will be found suitable. The rosin and wax, fully melted and heated almost to boiling, are poured over the wire from a ladle, turning the coil round, and repeating the application until the mixture has completely permeated the strands and filled up all the interstices between the wires. If this be done neatly, the paper covering may not be required. When the rosin mixture is employed as the insulating material, it is convenient to wind the wires on the cylinder, and insulate before the reel-ends are fixed on.

Secondary Coil.—This is formed of No. 38 copper wire, covered with silk, and averaging 180 yd. to the oz.; the quantity required is about 6 oz. In winding on the reel, scrupulous care is needed, to avoid any break in the wire, and any kink or bend in it. The diameter of this wire is ·0067 in. The layers of the secondary wire should not be carried close up to the end of the primary coil, thus avoiding the possibility of the wire of one layer sinking down to the level of that below it. When a layer of wire is finished and insulated, it is next to impossible to take it off again; consequently every care

must be taken to prevent any failure in winding it on. One layer of the secondary wire is wound on at a time, and then coated with the shellac varnish or rosin mixture. When done, the layer is further insulated by wrapping round several thicknesses of guttapercha tissue, or thin white demy paper soaked in the rosin mixture, and allowed to become hard. Whichever material be used, it is cut in strips a little wider than the length of the layer of wire it is to cover, and wound on tightly but smoothly. The length of the strip should be such as to wrap 3 or 4 times round the coil; it is fastened with the varnish or rosin mixture. When the requisite quantity of wire is put on, 8 or 10 folds of the insulating paper or tissue are wrapped round the coil before the ornamental covering of silk velvet is applied. If the wires forming the coil have been put on before the reel-ends have been fixed to the inner paper cylinder, the reel-ends must now be put in place, and, when firmly set, the spaces between the ends of the layers of wire and the inside of the reel-ends are filled up with the rosin mixture so that the insulation may be perfect. The winding of the secondary wire begins at the opposite end of the coil to that at which the winding of the primary coil commenced, and finishes at the end where it began. The 2 ends of the wire are wound into helices, and these can be passed through 2 holes in the reel-ends, in order that they may be connected with the other part of the apparatus.

Before winding the secondary wire, it is tested in the following way:—Attach one end of the wire on the bobbin (as it comes from the covers) to one electrode of a battery, and the other end to one of the binding screws of a galvanometer. The circuit is completed by uniting the other electrode of the battery with the other binding screw of the galvanometer, and if there be no break in the wire, a deflection of the needle will ensue. Should no deflection take place, the wire must be unwound from the bobbin, carefully examined, and the break detected and soldered. When the continuity of the wire has been effected, winding it on to the reel can be commenced. Each layer, as wound on, and before insulated, should be tested by the galvanometer. For this operation a different course is adopted. The beginning of the secondary wire on the reel is connected with one of the binding-screws of the galvanometer, and the end of the wire that still remains on the bobbin is attached to the other binding screw, as in Fig. 62.

FIG. 62.



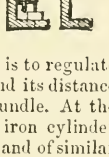
The 2 ends of the primary coil are connected with the battery, and if there be no fault, the needle of the galvanometer will be deflected; the layer can then be insulated, and the same course adopted with each layer. To solder 2 ends of the secondary wire together, the silk coating must be removed from each end—the ends brightened by rubbing with fine glass paper, put side by side in contact with each other, a small piece of tinfoil wrapped round both wires, moistened with a solution of zinc chloride, and moved over the flame of a very small spirit-lamp; in a few seconds, the tinfoil melts and unites the wires. Should it be necessary to apply the wires again to the lamp, they are first moistened with a fresh portion of zinc chloride. The wires should overlap each other about ½ in.; when the soldering is complete, the silk covering is carefully replaced.

Iron Bundle.—This is a bundle of uncovered iron wires, about No. 18 gauge, quite straight, of exactly equal lengths, and about ½ in. longer than the outside measurement of the coil. The centre of the coil is filled with these wires;

and then a short piece of larger wire, carrying on one end an iron disc about ¼ in. thick and ⅝ in. diameter, is pushed into the centre of the coil at each end, so as to secure the bundle in place.

Contact-breaker.—The form used for intensity coils is the vibrating contact-breaker. It is not desirable to use a separate electro-magnet for intensity coils, as a resistance is offered by it to the passage of the battery current; therefore the iron bundle in the coil, which becomes an electro-magnet, is used instead. This necessitates an alteration in the position of the spring and iron clapper, which, as shown in Fig. 63, are placed vertically. The spring is fixed to a brass block attached to the pedestal, having a vertical plate rising on one side. A screw passes through this plate and comes into contact with the spring a little way above its point of fixation to the block; the use of this screw is to regulate the tension of the spring and its distance from the end of the iron bundle. At the top end of the spring is an iron cylinder or clapper about ½ in. long, and of similar diameter; the spring is adjusted so that the face of this cylinder may, when the spring is at rest, be about ¼ in. from the end of the bundle. A strong brass pillar rises up also from the pedestal, and reaches a little above the centre of the coil. Through the top of this pillar a strong screw (the platinum screw) passes, carrying on its end a piece of platinum, which comes into contact with the spring where the iron cylinder is attached to it. The spring at this part is armed with platinum, and it is here that the contact is made and broken. The platinum screw is provided with a running boss, so that, when the screw is adjusted, the boss can be brought up tightly against the pillar, and thus prevent the screw from shifting. The surfaces of the platinum require to be smoothed and scraped from time to time, in order to maintain complete contact.

FIG. 63.



Condenser.—This is usually shut up in the cavity of the pedestal, though it can be separate. Its purport is to add to the energy of the current that traverses the primary wire, and consequently to increase the force of the secondary discharge. It consists of a number of tinfoil plates, separated by sheets of carefully varnished or rosinized paper, the alternate tinfoil plates being joined, thus forming 2 separate insulated series. One is connected with the pillar of the contact-breaker that carries the platinum screw, and the other with the block that holds the vibrating spring: these plates do not form part of the battery circuit, but are, as it were, lateral expansions of that circuit, on each side of the contact-breaker. The insulating sheets between the tinfoil plates thus have their electrical condition disturbed; when the battery circuit is interrupted, the plates return to their normal state, and in so doing, increase the action of the current circulating in the primary wire. The paper for separating the plates should be moderately thin, not too heavily sized, cut into pieces rather larger than is required, dipped into a solution of 1 oz. shellac dissolved in 6 oz. methylated spirit, hung up to dry for some hours, and examined; if the minutest pinhole be observed in any sheet, it must be rejected. A second coating of shellac varnish is applied, and when thoroughly dry, the paper is cut to the proper size, and preserved in a portfolio for use. For rosinized paper, ordinary tissue-paper does well, but white demy is better.

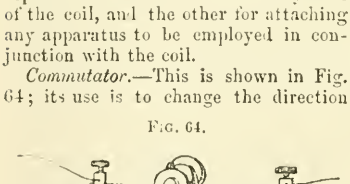
The condenser is made thus:—Prepare 50 sheets of tinfoil 5 in. long and wide, 60 pieces of insulating paper 7 in. by 5 in., and 2 thin mahogany boards of rather smaller size, varnished on each side. One board is laid down, and upon it 5 insulating papers are placed, then 1 tin-foil plate, taking care that 1 in. of the latter projects over one side of the varnished paper. Another paper is laid on this, coinciding in position with the first; on this comes a second tinfoil plate, but with the overhanging part at the opposite side. This is covered

with an insulating paper, and followed by the other plates in similar order. When done, 5 more papers are laid on, then the second mahogany board, and the whole is tied up with guttapercha string. All the projecting tinfoils at one side are pressed together, also those at the other side; the condenser is then ready to be placed in the cavity of the pedestal.

Pedestal.—This is made 13 in. long, 8 in. wide, and 2 in. deep. The bottom is movable, and fixed by screws or buttons. The coil is placed horizontally in the centre; holes are made in the top, in order to fix the coil in position. Other holes allow the ends of the primary wires, together with the pillars and binding screws, to be passed through, in order to attach them underneath. The contact-breaker is fixed at one end of the coil, and 2 binding-screws are fitted to the same end of the pedestal; at the other end are 2 ebonite pillars, 6 in. high and about $\frac{1}{2}$ in. diameter. If the ebonite be cut off about 1 in. longer than required, the extra can be turned down to a pin $\frac{1}{4}$ in. diameter, and a screw cut on its end. The holes in the pedestal are made sufficiently large to allow these pins to pass through, and the pillars can be firmly fixed by putting a nut on the under side. On top of each pillar is a binding-screw with 2 holes and separate screws to each; one for the reception of an end of the secondary wire of the coil, and the other for attaching any apparatus to be employed in conjunction with the coil.

Commutator.—This is shown in Fig. 64; its use is to change the direction

FIG. 64.



of the currents through the primary and secondary circuits. It consists of an ivory or ebonite cylinder, 1 in. long and 1 in. diameter. Metallic axes project from each end in separate pieces, 2 brass plates $\frac{3}{4}$ in. wide are fixed to opposite sides of the cylinder, one connected with each axis. The cylinder is supported horizontally on 2 brass blocks or pillars fixed to the base-board; and 2 brass springs rise up from the board and press on the brass plates on the face of the cylinder. Of the 4 binding-screws on the board, 2 are connected with the 2 springs by wires passing underneath or over the base-board, and the other 2 with the blocks carrying the axes of the cylinder. One axis projects through the block in which it rests, and on it is fitted an ivory or ebonite plate, to enable the cylinder to turn round. Two of the binding-screws on the board are connected with the battery, and the other 2 with the apparatus to be operated with.

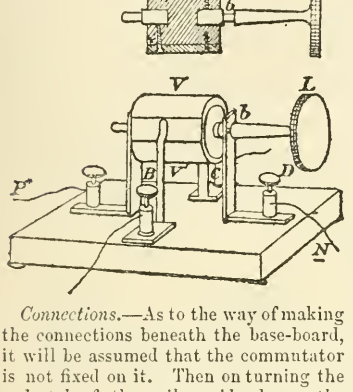
The current passes from the anode of the battery, through one binding-screw of the commutator, under or over the board, to one of the springs, up this to the plate on the cylinder it is in contact with, to the first axis, through the block in which the axis rests, and out by the binding-screw connected with that block to the apparatus, returning by the other spring plate and axis to the battery. When the cylinder is turned half round, without any other change in the arrangement, the current will pass in the opposite direction, still from the anode of the battery to the first spring, but thence to the second axis.

If the commutator be mounted on the pedestal, separate stand and binding-screws will not be required. It is capable of being used also as a current suspender: if the cylinder be turned only $\frac{1}{4}$ revolution, the springs rest upon the interspace between the 2 brass plates, and contact is broken. This should be done while the arrangements for the secondary current are being made, to avoid receiving a shock.

Fig. 65 shows Ruhmkorff's commutator. The battery poles are connected through the ends of the axis of a small ebonite or ivory cylinder to 2 brass cheeks, V V', which can be turned so as to place them either way

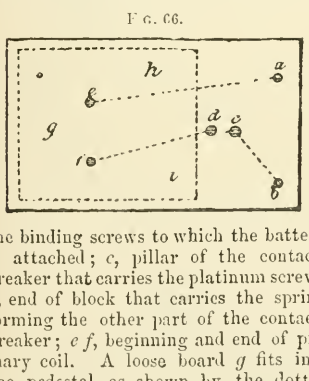
in contact with 2 vertical springs B C, which are joined to the ends of the primary coil.

FIG. 65.



Connections.—As to the way of making the connections beneath the base-board, it will be assumed that the commutator is not fixed on it. Then on turning the pedestal of the coil upside down, the under side will present the appearance shown in Fig. 66 : *a b* are the ends of

FIG. 66.



the binding screws to which the battery is attached; *c*, pillar of the contact-breaker that carries the platinum screw; *d*, end of block that carries the spring forming the other part of the contact-breaker; *e f*, beginning and end of primary coil. A loose board *g* fits into the pedestal, as shown by the dotted lines, and is fixed about half-way up from the bottom. This is required to lay the condenser on, and to afford convenient means for attaching it. On it, at *h i*, 2 flat brass plates, about 1 in. square, are fixed, having a screwed pin in the centre of each. These are for connecting the condenser with the contact-breaker. The various screws project through the top of the pedestal fully $\frac{3}{8}$ in. to enable nuts to be screwed over them. Strips of sheet copper, about $\frac{1}{2}$ in. wide, are prepared, 2 having a hole at one end and binding-screw at the other, and the third having a hole at each end. This latter is long enough to connect *b* and *c*, by dropping it over their projecting screws, and screwing a nut down tightly on the copper, securing the strip, and making the contact. The strips with binding-screws are used to connect *a e* and *d f*, the binding-screws securing the wires *e f*, and the holes in the copper strips enabling them to pass over the projecting screws *d a*, where they are fixed by nuts. When the anode of the battery is attached to the binding-screw at *a*, and the cathode to that at *b*, the current will flow through the coil. The circuit is complete in the direction of the dotted line *a e*, through the primary coil, out at *f*, then from *f* to *d*, through the contact-breaker to *c*, and from *c* to *b*.

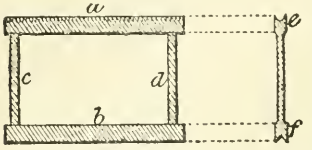
The condenser is laid on the loose board *g*, with the projecting tinfoils resting on the brass plates *h i*, a hole being punched through each set of tinfoils to admit the screw-pin; a brass plate is then laid on the top of the tinfoils, and by means of a nut on the screw-pin they are pressed closely together. When the condenser has been fitted in place, the nuts are loosened, the top brass plate is taken off, and 2 copper strips with holes at each end are fitted over the pins. These copper strips must be long enough to connect the pin *h* of the condenser with *c* of the contact-breaker and the pin *i* with *d*; this done, the nut is screwed up again. If the condenser is not thick enough to fill the space between the loose board and the bottom, the latter is padded, so that it will press on the former, and prevent it from shifting.

Coils, Resistance.—These consist of coils of wire (German silver or silver-iridium alloy), wound with great care, and of a length to have a resistance of a definite number of ohms.

The following instructions for making

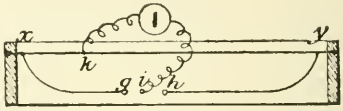
a set of resistance coils, simple yet reliable, are easily within the reach of any one possessing the few requisite tools. The coils themselves consist of wooden frames (preferably oak), as shown in Fig. 67: *a b* are 6 in. long, $\frac{1}{2}$ in. deep,

FIG. 67.



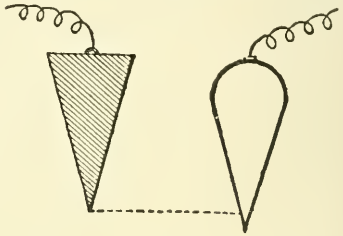
and rather over $\frac{1}{4}$ in. thick; joining them are *c d*, also of oak, $\frac{1}{2}$ in. deep, and rather thinner than *a b*, so that they do not come up flush with *c f*. The tops of *a b* are grooved, as shown at *c f*; and at intervals (varying with the size of wire used) are cut notches as shown along *a*, for the wire to be wound into. If the wires are not larger than 24 or 26 BWG, they may be about $\frac{1}{8}$ in. apart. The number of frames is regulated by the number of ohms resistance required to be made up. Upon the frames is wound uninsulated German silver wire, such as may be bought at any metal warehouse. One end is fixed by a screw to a point on *c*, and winding is commenced, keeping the wire tight, and taking care that it goes to the bottom of the notches cut for it. When the coils are not likely to be subjected to very powerful currents, No. 28 wire may be commenced with for the smaller resistances, gradually progressing to No. 40 as the resistances increase. When the frames are wound, they are soaked in hot paraffin wax till thoroughly saturated, and the excess is drained off. The next step is to give the coils their true value, according to some available standard. For this is required a simple form of Wheatstone bridge, such as that shown in Fig. 68, and made in the following way:—On a board about 5 ft. long fix a piece of wood about $\frac{1}{2}$ in. thick at each end. From the tops of these pieces of wood tightly stretch a piece of German silver wire, and firmly fix it by screws. To 2 points *x y* near the ends of the German silver wire, solder 2 stout copper wires, leading to 2 binding-screws *g h*; at *i*, between

FIG. 63



them, is another screw. Make 2 clips of stout brass, as shown in elevation and section in Fig. 69; to one of these solder any piece of copper wire, and to the other a stout piece. Place the clip with

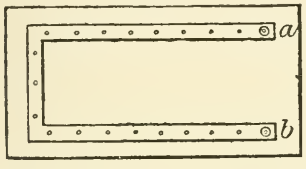
FIG. 69.



the thin wire so that it clips the wire *x y* at any point; let the wire connected with it go to one terminal of an astatic galvanometer, whilst the other terminal of the galvanometer is connected with *i*. Let the standard, which may be a piece of wire having a resistance of 1 ohm, be placed between *g i*, and to *h* connect the end of the wire on one of the coils just wound. Connect a battery to *xy*, about 6 Daniell cells, though less may do. Supposing it is wished to find what point of the wire on the coils gives 5 ohms: divide the wire *xy* into 6 parts, and set the clip so that 5 parts are on one side and 1 on the other; then *xk* : *ky* : : 1 : 5, and the 1 ohm standard is between *g* and *i*. Now, having *h* connected to one end of a coil, connect the end of the stout wire on the other clip to *i*, and put the clip on different points of the wire wound on the coil till no deflection is got on the galvanometer: this point shows the ends of the 5 ohms, and to it a stout copper

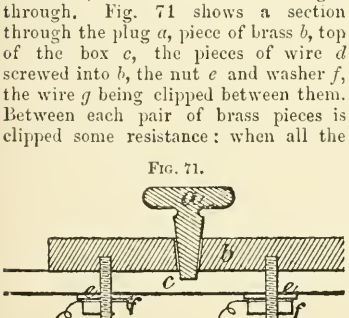
wire is soldered. Similar trials, altering the ratio of xk to ky, will enable any number of ohms' resistance to be accurately marked out. This done, a box is made rather larger than the frames of the coils, and into it the coils are put, first fixing pieces of cork at the corners, so that no contact takes place between the coils. On the top of the box, as shown at *a*, Fig. 70, is placed a piece of

FIG. 70.



stout brass, $\frac{1}{2}$ in. by $\frac{1}{4}$ in.; holes are bored at intervals of about 1 in., made tapering with a reamer, and fitted with tapering brass plugs. Binding-screws are fixed at *ab*; underneath, between every 2 holes, a small hole is bored, and a short piece of wire is screwed in and fitted with a brass nut and washer; these serve both to bolt down the piece of brass and for fixing the resistance coil wire to. Finally, across the centre of each hole, the brass is sawn right through. Fig. 71 shows a section through the plug *a*, piece of brass *b*, top of the box *c*, the pieces of wire *d* screwed into *b*, the nut *e* and washer *f*, the wire *g* being clipped between them. Between each pair of brass pieces is clipped some resistance: when all the

FIG. 71.



plugs are in, the current will go from *ab* (Fig. 70) round by the thick brass at the top; if a plug is drawn, the current has to pass through the resistance that connects the 2 brass pieces thus left without a plug. It is convenient to have plugs putting in the following resistances:—1, 2, 2, 5, 10, 10, 20, 50, 100, 100, 200, 500, thus giving any integer between 1 and 1000.

Dynamo-electric Machines.—The following description of dynamo-electric machinery is mainly derived from a series of Cantor Lectures by Prof. Silvanus Thompson, delivered before the Society of Arts in December, 1882.

A dynamo-electric machine is an apparatus for converting energy in the form of dynamical power into energy in the form of electric currents, by the operation of setting conductors, usually in the form of copper wire coils, to rotate in a magnetic field. From a consideration of the principles underlying dynamo-electric machines, Prof. Thompson formulates the following summary:—

(1) A part at least of the energy of an electric current exists in the form of magnetic whirls in the space surrounding the conductor.

(2) Currents can be generated in conductors by setting up magnetic whirls round them.

(3) Magnetic whirls can be set up in conductors by moving magnets near them, or moving them near magnets.

(4) To set up and maintain such magnetic whirls requires a continuous expenditure of energy; *i.e.* consumes power.

(5) To induce currents in a conductor, there must be relative motion between conductor and magnet of such kind as to alter the number of lines of force embraced in the circuit.

(6) Increase in the number of lines of force embraced by the circuit produces a current in the opposite sense to decrease.

(7) Approach induces an electromotive force in the opposite direction to that induced by recession.

(8) The more powerful the magnet-pole or magnetic field, the stronger will be the current generated (other things being equal).

(9) The more rapid the motion, the stronger will be the currents.

(10) The greater the length of the moving conductor thus employed in cutting lines of force (*i. e.* the longer the bars, or the more numerous the turns of the coil), the stronger will be the currents generated.

(11) The shorter the length of those parts of the conductor not so employed, the stronger will be the current.

(12) Approach being a finite process, the method of approach and recession (of a coil towards and from a magnet pole) must necessarily yield currents alternating in direction.

(13) By using a suitable commutator, all the currents, direct or inverse, produced during recession or approach, can be turned into the same direction in the wire that goes to supply currents to the external circuits, thereby yielding an almost uniform current.

(14) In a circuit where the flow of currents is steady, it makes no difference what kind of magnet is used to procure the requisite magnetic field, whether permanent steel magnets or electro-magnets, self-excited or otherwise.

(15) Hence the current of the generator may be itself utilized to excite the magnetism of the field-magnets, by being caused, wholly or partially, to flow round the field-magnet coils.

Many varieties of dynamo-electric machine have been constructed upon the foregoing principles. Prof. Thompson distinguishes 3 main classes:—

I.—Dynamos in which there is rotation of a coil in a uniform field of force, such rotation being effected round an axis in the plane of the coil, or one parallel to such an axis. Examples: Gramme, Siemens (Alteneck), Edison, Lontin, Bürgin, Fein, Schückert, Jürgensen (Thomson's Mousemill-dynamo), [Brush].

II.—Dynamos in which there is translation of coils to different parts of a complex field of varying strength or of opposite sign. Most machines of this class furnish alternate currents. Examples: Pixii, Clarke, Niaudet, Wallace, Farmer, Wilde (alternate), Siemens (alternate), Hopkinson and Muirhead, Thomson (alternate), Gordon (alternate), Siemens-Alteneck (Disk Dynamo), Edison (Disk Dynamo), De Meritens.

III.—Dynamos having a conductor rotating so as to produce a continuous increase in the number of lines of force cut, by the device of sliding one part of the conductor on or round the magnet, or on some other part of the circuit. Examples: Faraday's Disk-machine, Siemens's ("Unipolar" Dynamo), Voice's Dynamo.

One machine does not fall exactly within any of these classes, and that is the extraordinary tentative dynamo of Edison, in which the coils are waved to and fro at the ends of a gigantic tuning-fork, instead of being rotated on a spindle.

A dynamo of any one of these plans must be constructed upon the following guiding lines:—

(*a*) The field-magnets as strong as possible, and their poles as near together as possible.

(*b*) The armature having the greatest possible length of wire upon its coils.

(*c*) The wire of the armature coils as thick as possible, so as to offer little resistance.

(*d*) A very powerful steam-engine to turn the armature, because,

(*e*) The speed of rotation should be as great as possible.

It is impossible to realize all these conditions at once, as they are incompatible with one another; and there are many additional conditions to be observed. Prof. Thompson deals with the various matters in order, beginning with the speed of the machine.

Relation of Speed to Power.—Theory shows that, if the intensity of the magnetic field be constant, the electromotive force should be proportional to the speed of the machine. This is true within certain limits, for machines in which the field magnets are independent of the main circuit, *i.e.* for magneto and separately-excited dynamos. It is not, however, quite exact, unless the resistance of the circuit be increased

proportionately to the speed, because the current in the coils itself reacts on the magnetic field, and alters the distribution of the lines of force. The consequence of this reaction is that (1) the position of the "diameter of commutation" is altered, and (2) the effective number of lines of force is reduced. So that, with a constant resistance in circuit, the electromotive force, and therefore the current, are slightly less at high speeds than the proportion of the velocities would lead one to expect. Since the product of current into electromotive force gives a number proportional to the electric work of the machine, it follows that, for "independently excited" machines, the electric work done in given time is nearly proportional to the square of the speed, and the work drawn from the steam-engine will be similarly proportional to the square of the speed. In self-exciting machines, whether "series" or "shunt" in their arrangements, a wholly different law obtains. If the iron of the field-magnets be not magnetized near to saturation, then, since the increase of current consequent on increase of speed produces a nearly proportional increase in the strength of the magnetic field, this increase will react on the electromotive force, and cause it to be proportional more nearly to the square of the velocity, which again will cause the current to increase in like proportion. But since the magnetization of the iron is, even when far from saturation point, something less than the magnetizing force, it is in practice found that the electric work of the machine is proportional only to something slightly less than the third power of the speed. As mechanical considerations limit the velocity of the moving parts, it is clear that, at the limiting speed at which it is safe to run any given armature, the greatest amount of work will be done by using the most powerful magnets possible—electro-magnets rather than steel. Deprez has found that for every dynamo there is a certain "critical" speed, at which, no matter what the current is which circulates in the coils of the field magnets, the electromotive force is proportional to the strength of that current; and he bases upon it 2 methods for obtaining, automatically, either a constant electromotive force or a constant current, at will, in a circuit in which the resistances are varied to any degree. In all these combinations, however, everything depends upon the condition that the driving speed shall be uniform. Gas engines are out of the question as a source of power; even with the best steam-engines a specially sensitive valve is required, and probably such valves will, in future, be operated electrically by self-acting electro-magnet gearing. Where the driving is at all liable to be uneven, the precaution should be taken of placing a heavy fly-wheel on the axis of the dynamo.

Field-magnets.—The coils of the field-magnets cannot be constructed of no resistance; thus they always waste some of the energy of the currents in heat. It has been argued that it cannot be economical to use electro-magnets in comparison with permanent magnets of steel, which have only to be magnetized once for all; but certain considerations tell in favour of electro-magnets. For equal power, their prime cost is less than that of steel magnets, which require remagnetizing at intervals. Moreover, as there is a limiting velocity at which it is safe to run a machine, it is important, in order not to have machines of needlessly great size, to use the most powerful field-magnets possible. But if it is more convenient to spend part of the current upon the electro-magnets, economy dictates that they should be so constructed that their magnetism may cost as little as possible. To magnetize a piece of iron requires the expenditure of energy; but when once it is magnetized, it requires no further expenditure of energy (save the slight loss by heating in the coils, which may be reduced by making the resistance of the coils as little as possible) to keep it so magnetized, provided the magnet is doing no work. Even if it be doing no work, if the current flowing round it be

not steady, there will be loss. If it do work, say, in attracting a piece of iron to it, then there is an immediate and corresponding call upon the strength of the current in the coils to provide the needful energy. In a dynamo, where, in many cases, are revolving parts containing iron, it is of importance that the approach of a recession of the iron parts should not produce such reactions as these in the magnetism of the magnet. Large slow-acting field-magnets are therefore advisable. The following points embody the conditions for attaining the end desired:—

(*a*) The body of the field-magnets should be solid. Even in the iron itself currents are induced, and circulate whenever the strength of the magnetism is altered. These self-induced currents tend to retard all changes in the degree of magnetization. They are stronger in proportion to the square of the diameter of the magnet, if cylindrical, or to its area of cross-section. A thick magnet will therefore be a slow-acting one, and will steady the current induced in its field.

(*b*) Use magnets having in them plenty of iron. It is important to have a sufficient mass, that saturation may not be too soon attained.

(*c*) Use the softest possible iron for field-magnets, not because soft iron magnetizes and demagnetizes quicker than other iron (that is here no advantage); but because soft iron has a higher magnetic susceptibility than other iron—is not so soon saturated.

(*d*) Use long magnets to steady the magnetism, and therefore the current. A long magnet takes a longer time than a short to magnetize and demagnetize. It costs more and requires more copper wire in the exterior coil; but the copper wire may be made thicker in proportion, and will offer less resistance. The magnetism so obtained should be utilized as directly as possible, therefore

(*e*) Place the field-magnets, or their pole-pieces, as close to the rotating armature as is compatible with safety in running.

(*f*) If the field-magnets or their pole-pieces have sharp edges, the field cannot be uniform, and some of the lines of force will run uselessly through the space outside the armature instead of going through it. Theoretically, the best external form to give to a magnet is that of the curves of the magnetic lines of force.

(*g*) Reinforce the magnetic field by placing iron, or, better still, electro-magnets, within the rotating armature. This is done by giving the armature coils iron cores which rotate with them; or the iron cores or internal masses may be stationary. In the former case, is loss by heating: in the latter, are structural difficulties to be overcome.

(*h*) In cases where a uniform magnetic field is not desired, but where, as in dynamos of the second class, the field must have varying intensity at different points, it may be advisable specially to use field-magnets with edges or points, so as to concentrate the field at certain regions.

Pole-pieces.—(*a*) The pole-pieces should be heavy, with plenty of iron in them, for reasons similar to those urged above.

(*b*) They should be of shapes adapted to their functions. If intended to form a single approximately uniform field, they should not extend too far on each side. The distribution of the electromotive force in the various sections of the coils on the armature depends very greatly on the shape of the pole-pieces.

(*c*) Pole-pieces should be constructed so as to avoid, if possible, the generation in them of useless Foucault currents. The only way of diminishing loss from this source is to construct them of laminæ, built up so that the mass of iron is divided by planes in a direction perpendicular to that of the currents, or of the electromotive forces tending to start such currents.

(*d*) If the bed-plates of dynamos are of cast-iron, care should be taken that these do not short-circuit the magnetic lines of force from pole to pole of the field-magnets. Masses of brass, zinc, or

other non-magnetic metal may be interposed; but are at best a poor resource. In a well-designed dynamo there should be no need of such devices.

Field-magnet Coils.—(*a*) To be of the greatest possible service, the coils of field-magnets should be wound on most thickly at the middle of the magnet, not distributed uniformly along its length, nor yet crowded about its poles. The reason for this is two-fold. Many of the lines of force of a magnet "leak out" from the sides of the magnet before reaching its poles, where they should all emerge if the mass of the magnet were perfectly equally magnetized throughout its whole length. Internally, the magnetization of the magnet is greatest at its centre. At or near the centre, therefore, place the magnetizing coils, that the lines of force due to them may run through as much iron as possible. The second reason for not placing the coils at the end is this: any external influence which may disturb the magnetism of a magnet, or affect the distribution of its lines of force, affects the lines of force in the neighbourhood of the pole far more than those in any other region.

(*b*) The proper resistances to give to the field-magnet coils of dynamos have been calculated by Sir Wm. Thomson, who has given the following results:—

For series dynamos, make the resistance of the field-magnets a little less than that of the armature. Both should be small compared with the resistance of the external circuit. The ratio of the waste by heating in the machine to the total electric work of the machine will be—

$$\frac{\text{waste:}}{\text{total work}} = \frac{R_M + R_A}{R_M + R_A + R_X}$$

and

$$\frac{\text{useful work}}{\text{total work}} = \frac{R_X}{R_M + R_A + R_X}$$

where R_M is the resistance of the magnets,

R_A is the resistance of the armature,

R_X is the resistance of the external circuit.

For a shunt dynamo the rule is different. The best proportions are when such that

$$R_X = \sqrt{R_M R_A}, \text{ or that}$$

$$R_M = \frac{R_X^2}{R_A}$$

also the ratio of useful work is—

$$\frac{\text{useful work}}{\text{total work}} = \frac{1}{1 + 2\sqrt{\frac{R_A}{R_M}}}$$

As an example of the latter, suppose it was wished that the waste should not be more than 10 per cent. of the useful work, the ratio of the formula must equal $\frac{10}{11}$, or $1 \div 1\frac{1}{10}$. Hence

$$\sqrt{\frac{R_A}{R_M}} \text{ must equal } \frac{1}{20};$$

or R_M the resistance of the field-magnets must be 400 times R_A that of the armature.

Armature Cores.—(*a*) Theory dictates that if iron is employed in armatures, it must be slit or laminated, so as to prevent the generation of Foucault currents. Such iron cores should be structurally divided in planes normal to the circuits round which electromotive force is induced; or should be divided in planes parallel to the lines of force and to the direction of the motion. Cores built up of varnished iron wire, or of thin disks of sheet-iron separated by varnish, asbestos paper, or mica, partially realize the required condition.

(*b*) Armature cores should be so arranged that the direction of polarity of their magnetization is never abruptly reversed during their rotation. If this precaution is neglected, the cores will be heated.

Armature Coils.—(*a*) All needless resistance should be avoided in armature coils, as hurtful to the efficiency of the machine. The wires should be as short and thick as is consistent with obtaining the requisite electromotive force, without requiring an undue speed of driving.

(*b*) The wire should be of the best electric conductivity. The conductivity of good copper is so nearly equal to that

of silver (over 96 per cent.), that it is not worth while to use silver wires in the armature coils of dynamos.

(*c*) In cases where copper rods or strips are used instead of wires, care must be taken to avoid Foucault currents by laminating such conductors, or slitting them in planes parallel to the electromotive force; *i.e.* in planes perpendicular to the lines of force and to the direction of the rotation.

(*d*) In dynamos of the first class, when used to generate currents in one direction, since the currents generated in the coils are doing half their motion inverse to those generated during the other half of their motion, a commutator or collector of some kind must be used. In any single coil without a commutator, the alternate currents would be generated in successive revolutions, if the coil were destitute of self-induction currents. But if by the addition of a simple split-tube commutator, the alternate halves of these currents are reversed, so as to rectify their direction through the rest of the circuit, the resultant currents will not be continuous, but will be of one sign only, there being 2 currents generated during each revolution of the coil. If 2 coils are used at right angles to each other's planes, so that one comes into the position of best action, while the other is in the position of least action (one being normal to the lines of force when the other is parallel to them), and their actions be superposed, the result will be to give a current which is continuous but not steady, having 4 slight undulations per revolution. If any larger number of separate coils is used, and their effects, occurring at regular intervals, be superposed, a similar curve will be obtained, but with summits proportionately more numerous and less elevated. When the number of coils used is very great, and the overlappings of the curves are still more complete, the row of summits will form practically a straight line, or the whole current will be practically constant.

(*e*) The rotating armature coils ought to be divided into a large number of sections, each coming in regular succession into the position of best action.

(*f*) If these sections, or coils, are independent of each other, each coil, or diametrical pair of coils, must have its own commutator. If they are not independent, but are wound on in continuous connection all round the armature, a collector is needed, consisting of parallel metallic bars as numerous as the sections, each bar communicating with the end of one section and the beginning of the next.

(*g*) In any case, the connections of such sections and of the commutators or collectors should be symmetrical round the axis; if not, the induction will be unequal in the parts that successively occupy the same positions with respect to the field-magnets, giving rise to inequalities in the electromotive force, sparking at the commutator or collector, and other irregularities.

(*h*) Where the coils are working in series, it is advantageous to arrange the commutator to cut out the coil that is in the position of least action, as the circuit is thereby relieved of the resistance of an idle coil. But no such coil should be short-circuited to cut it out. Where the coils are working in parallel, cutting out an idle coil increases the resistance, but may be advisable to prevent heating from waste currents traversing it from the active coils.

(*i*) In the case of pole-armatures, the coils should be wound on the poles rather than on the middles of the projecting cores; since the variations in the induced magnetism are most effective at or near the poles.

(*j*) Since it is impossible to reduce the resistance of the armature coils to zero, it is impossible to prevent heat being developed in those coils during their rotation; hence it is advisable that the coils should be wound with air spaces in some way between them, that they may be cooled by ventilation.

(*k*) The insulation of the armature coils should be ensured with particular care, and should be carried out as far as possible with mica and asbestos, or

other materials not liable to be melted, if the armature coils become heated.

Commutators, Collectors, and Brushes. —(*a*) Commutators and collectors, being liable to be heated through imperfect contact, and liable to be corroded by sparking, should be made of very substantial pieces of copper.

(*b*) In the case of a collector made of parallel bars of copper, ranged upon the periphery of a cylinder, the separate bars should be removable singly, to admit of repairs and examination.

(*c*) The brushes should touch the commutator or collector at the 2 points, the potentials of which are respectively the highest and the lowest of all the circumference. In a properly and symmetrically built dynamo, these points will be at opposite ends of a diameter.

(*d*) In consequence of the armature itself, when traversed by the currents, acting as a magnet, the magnetic lines of force of the field will not run straight across from pole to pole of the field-magnets, but will take, on the whole, an angular position, being twisted a considerable number of degrees in the direction of the rotation. Hence the diameter of commutation (which is at right angles to the resultant lines of force in machines of the Siemens and Gramme type, and parallel to the resultant lines of force in machines of the Brush type), will be shifted forward. In other words, the brushes will have a certain angular lead. The amount of this lead depends upon the relation between the intensity of the magnetic field and the strength of the current in the armature. This relation varies in the 4 different types of field-magnets. In the series dynamo, where the one depends directly on the other, the angle of lead is nearly constant, whatever the external resistance. In other forms of dynamo, the lead will not be the same, because the variations of resistance in the external circuit do not produce a proportionate variation between the 2 variables which determine the angle of lead.

(*e*) Hence in all dynamos it is advisable to have an adjustment enabling the brushes to be rotated round the commutator or collector, to the position of the diameter of commutation for the time being. Otherwise there will be sparking at the brushes, and in part of the coils at least the current will be wasting itself by running against an opposing electromotive force.

(*f*) The arrangements of the collector or commutator should be such that, as the brushes slip from one part to the next, no coil or section in which there is an electromotive force should be short-circuited, otherwise work will be lost in heating that coil. For this reason, it is well so to arrange the pole-pieces that the several sections or coils on either side of the neutral position should differ but very slightly in potential from one another.

(*g*) The contact points between the brushes and the collector, or commutator, should be as numerous as possible, for, by increasing the number of contacts, the energy wasted in sparks will be diminished inversely as the square of that number. The brushes might with advantage be laminated, or made of parallel loose strips of copper, each bearing edgeways on the collector.

Relation of Size to Efficiency.—The efficiency of a dynamo is the ratio of the useful electrical work done by the machine to the total mechanical work applied in driving it. Every circumstance which contributes to wasting the energy of the current reduces the efficiency of the machine. It has been shown what the chief electric sources of waste are, and how they may be avoided. Mechanical friction of the moving parts can be minimized also by due mechanical arrangements. But even the best conductors have a certain resistance, and it is impossible to prevent the heating of the conducting coils; the more powerful the current generated by the machine, the more important does this source of waste become. The one way to reduce this is by increasing the size of the machines. For some years, Prof. Thompson has advocated large dynamo machines, because the larger machines may be made more efficient than the small, in

proportion to their cost. In discussing the relation of size to efficiency, he assumes, for the sake of argument, that the size of any machine can be increased n times in every dimension, and that, though the dimensions are increased, the velocity of rotation remains the same, and that the intensity of the magnetic field per square centimetre remains also constant. If the linear dimensions be n times as great in the larger as in the smaller, the area it stands on will be increased n^2 times, and its volume and weight n^3 times. The cost will be less than n^3 times, but greater than n times. If the same increase of dimensions in the coils be observed (the number of layers and of turns remaining the same as before), there will be in the armature coils a length n times as great, and the area of cross-section of the wire will be n^2 times as great as before. The resistance of these coils will therefore be but $\frac{1}{n}$ part of the original resistance of the smaller machine. If the field-magnet coils are increased similarly, they will offer only $\frac{1}{n}$ of the resistance of those of the smaller machine. Moreover, seeing that while the speed of the machine is the same, the area cut through by the rotating coils is increased n^2 times, these coils will in the same time cut n^2 times as many lines of force, or the electromotive force will be increased n^2 times. Supposing the whole of the circuit to be similarly magnified, its resistance will also be but $\frac{1}{n}$ of the previous value.

If the machine is a "series-wound" dynamo, an electromotive force n^2, working through $\frac{1}{n}$ resistance, will give a current n^2 times as great as before. Such a current will, as a matter of fact, much more than suffice to bring up the magnetic field to the required strength, viz., n_2 times the area of surface magnetized to the same average intensity per square centimetre, as stipulated; for the mass of iron being n^3 times as great, it need not be so much saturated as before to give the required field. Here an economy may be effected, therefore, by further reducing the number of coils, and therefore the wasteful resistance of the field-magnet coils, in the proportion of n^3 to n^2, or to $\frac{1}{n}$ of its already diminished value. Even if this were not done, by the formula given above for the electrical efficiency of a "series" dynamo, the waste, when working through a constant external resistance, will be n-fold less than with the smaller machine. Now, if the current be increased n^2 times, and the electromotive force n^2 times, the total electric work which is the product of these will be n^5 times greater than in the small machine, and it will consume n^5 times as much power to drive it. It is clearly an important economy, if a machine costing less than n^3 times as much, will do n^5 times as much work (to say nothing of the increased ratio of efficiency). A machine doubled in all its linear dimensions will not cost 8 times as much, and will be electrically 32 times as powerful.

Suppose the machine to be "shunt" wound, then to produce the field of force of n^2 times as many square centimetres area, will require (if the electromotive force be n^2 times as great) that the absolute strength of the current remain the same as before in the field-magnet coils. This can be done by using the same sized wire as before, and increasing its length n^2 times, to allow for n times as many turns, of n times as great a diameter each, in the same number of layers of coils as before. In this case the work done in the shunt, being equal to the product of the n^2-fold electromotive force into the unaltered current, will be only n^3 times as great, while the whole work of the machine is augmented n^5 times. If, while augmenting the total work n^5 times, the waste work is increased only n^2 times, it is clear that the ratio of waste to the total effect is diminished n^3-fold. There is, therefore, every reason to construct large machines,

from the advantage of economy both in relative prime cost and relative efficiency.

Methods of exciting Field-Magnetism.—There are certain theoretical considerations respecting the method of exciting the magnetism of the field in which the armatures are to revolve. The main methods are 4 in number.

Magneto-Dynamos.—Magneto-dynamos have the advantage in theory that their electromotive force is very nearly exactly proportional to the velocity of rotation; though, of course, the variable difference of potential between the terminals of the machine depends on the relation of the resistance of the external circuit to the internal resistance of the armature coils. They possess the disadvantage that, since steel cannot be permanently magnetized to the same degree as that which soft iron can temporarily attain, they are not so powerful as other dynamos of equal size.

Separately-excited Dynamos.—The separately-excited dynamo has the same advantage as the magneto-machine, in its electromotive force being independent of accidental changes of resistance in the working circuit, but is more powerful. It has, moreover, the further advantage that the strength of the field is under control, for, by varying either the electromotive force or the resistance in the exciting circuit, the strength of the magnetic field is varied at will. It has the disadvantage of requiring a separate exciting machine.

Series Dynamos.—The ordinary or series dynamo is usually a cheaper machine, for equal power, than any other form, as its coils are simpler to make than those of a shunt machine, and it wants no auxiliary exciter. It has the disadvantages of not starting action until a certain speed has been attained, or unless the resistance of the circuit is below a certain minimum. It is also liable to become reversed in polarity, a serious disadvantage when this machine is applied for electroplating or for charging accumulators. From its arrangements, any increase of the resistance in the circuit lessens its power by diminishing the strength of its magnetic field. Hence it is better adapted for use with lamps arranged in parallel arc than for lamps arranged in series. An additional lamp switched in, in series, adds to the resistance of the circuit, and diminishes the power of the machine to supply current; while, on the other hand, an additional lamp in parallel reduces the total resistance offered by the network of the circuit, and adds to the power of the machine to provide the needed current. It is easy to regulate the currents given by a series dynamo, by introducing a shunt of variable resistance across the field-magnet, thus altering the magnetizing influence of the current.

Shunt Dynamos.—The shunt dynamo has several advantages over other forms. It is less liable to reverse its polarity than the series dynamo, and it is commonly considered as providing the magnetizing power to the magnets with less waste of current. Moreover, for a set of lamps in series, its power to supply the needful current increases with the demands of the circuit, since any added resistance sends additional current round the shunt in which the field-magnets are placed, and so makes the magnetic field more intense. On the other hand, there is greater sensitiveness to inequalities of driving, in consequence of the self-induction in the shunt. The shunt part of the circuit in the present case consists of a fine wire of many turns, wound upon iron cores. It therefore has a much higher co-efficient of self-induction than the rest of the circuit; and consequently any sudden variations in the speed of driving can but affect the current in the main circuit more than in the shunt. Briefly, the shunt-winding, though it steadies the current against perturbations due to changes of resistance in the circuit, does not steady the current against perturbations due to changes in driving speed. In the series-wound dynamo, the converse holds good.

Any of these systems may be applied either in direct current or in alternate current machines. Each has its own merits for special cases, but none is

perfect. Not one will ensure that, with uniform driving speed, either the electromotive force of the current shall be constant, however the resistances of the circuit are altered.

There is no such thing yet as a best dynamo. One gives steadier currents, another is less liable to heat, a third is more compact, a fourth is cheaper, a fifth is less likely to reverse its currents, a sixth gives a greater volume of current, while a seventh evokes a higher electromotive force.

Combination Methods.—A method of rendering a dynamo automatically self-adjusting, so that either its electromotive force or its current (according to circumstances) shall be constant, is due to Deprez. If a dynamo be wound with a double set of coils, one of which can be traversed by an independent current, whilst the other is traversed by the current of the machine itself, there can always be found a certain critical velocity of driving, for which, provided the field-magnets are far from attaining their saturation point, the desired condition is fulfilled. Other combination methods have been suggested, and a summary of them follows.

(1) Series and Separate (for Constant E.M.F.), Deprez.—This method can be applied to any ordinary dynamo, provided the coils are such that a separate current from an independent source can be passed through a part of them, so that there shall be an initial magnetic field, independent of the main-circuit current of the dynamo. When the machine is running, the electromotive force producing the current will depend partly on this independent excitement, partly on the current's own excitement of the field-magnets. If the machine be run at such a speed that the quotient of the part of the electromotive force due to the self-excitement, divided by the strength of the current, is numerically equal to the internal resistance of the machinery, then the electromotive force in the circuit will be constant, however the external resistances are varied. This velocity can be deduced from experiment, and when the critical velocity has once been determined, the machine can be adjusted to work at any desired electromotive force, by varying the strength of the separately-exciting current to the desired degree.

(2) Shunt and Separate (for Constant Current), Deprez.—When cases arise, as for a set of arc lamps in series, that it is desired to maintain the current in the circuit at one constant strength, the previous arrangement must be modified by combining a shunt-winding with coils for a separately-exciting current. This arrangement is, in fact, that of a shunt-dynamo, with an initial magnetic field independent of the strength of the current in the circuit. Seeing that the only object in providing the coils for separate excitement is to secure an initial and independent magnetic field, it is clear that other means may be employed to bring about a similar result.

(3) Series and Magneto (Constant E.M.F.), Perry.—The initial electromotive force in the circuit, required by Deprez's theory, need not necessarily consist in there being an initial magnetic field of independent origin. It is true that the addition of a permanent magnet, to give an initial partial magnetization to the pole-pieces of the field magnets, would meet the case to a certain extent; but Prof. Perry has adopted the more general solution of introducing into the circuit of a series-dynamo a separate magneto machine, also driven at a uniform speed, such that it produces in the circuit a constant electromotive force equal to that which it is desired should exist between the leading and return mains. This arrangement may be varied by using a shunt-wound dynamo, the magnets being, as before, included in the part of the circuit outside the machines.

(4) Shunt and Magneto (Constant Current), Perry.—Perry's arrangement for constant current consists in combining a shunt-dynamo with a magneto machine of independent electromotive force, this magneto machine being inserted either in the armature part or in the magnet-shunt part of the machine. As before, a certain critical speed must be found from experiment and calculation.

(5) Series and Shunt.—A dynamo having its coils wound so that the field-magnets are excited partly by the main current, partly by a current shunted across the brushes of the machine, is not so perfect as either of the preceding, being more limited in operation. If the shunt coils be comparatively few and of high resistance, so that their magnetizing power is small, the machine will give approximately a uniform electromotive force; whereas, if the shunt be relatively a powerful magnetizer, as compared with the few coils of the main circuit, the machine will be better adapted for giving a constant current; but, as before, each case will correspond to a certain critical speed, depending on the arrangements of the machine.

(6) Series and Long Shunt.—Prof. Thompson gives this name to a combination closely resembling the preceding. If the magnets are excited partly in series, but also partly by coils of finer wire, connected as a shunt *across the whole external circuit*, then the combination should be more applicable than the preceding to the case of a constant electromotive force, since any variation in the resistance of the external circuit will produce a greater effect in the "long shunt" than would be produced if the resistance of the field-magnets were included in the part of the main circuit external to the shunt. Although the last 2 combinations are not such perfect solutions of the problem as those which precede, they are more likely to find immediate application, since they can be put into practice upon any ordinary machine, and do not require, as in the first 4 combinations, the use of separate exciters, or of independent magneto-machines.

All these arrangements presuppose a constant velocity of driving; but they are not the only ones consistent with this condition. An ordinary series dynamo may be made to yield a constant current, by introducing across the field-magnets a shunt of variable resistance, the resistance of the shunt being adjusted automatically by an electro-magnet whose coils form part of the circuit. This is actually done in the automatic regulator attached to Brush dynamos, as used in supplying a series of arc lights. A shunt-dynamo may similarly be controlled, so as to yield a uniform electro-motive force, by introducing a variable resistance into the shunt-magnet circuit as is done in some of Edison's dynamos. To make the arrangement perfect, this variable resistance should be automatically adjusted by an electro-magnet whose coils are an independent shunt across the mains of the external circuit. Yet another way of accomplishing the regulation of dynamos is possible in practice, without the condition of a constant speed of driving. Let the ordinary centrifugal governor of the steam-engine be abandoned, and let the supply of steam be regulated, not by the condition of the velocity of driving, but by means of an electric governor, such as an electro-magnet working against an opposing spring. If this electro-magnetic governor is to maintain a constant electromotive force, its coils must be a shunt to the mains of the circuit. If it is to maintain a constant current, its coils must be part of the main circuit. Such a governor ought to be more reliable and rapid than any centrifugal governor intended to secure a uniform speed of driving.

Organs of Dynamos as constructed in practice.—Field-Magnets.—In the classification of dynamos, those of the first class required a single approximately uniform field of force, whilst those of the second required a complex field of force differing in intensity and sign at different parts. Hence a corresponding general demarcation between the field-magnets in the 2 classes of machine. In the first, are usually 2 pole-pieces on opposite sides of a rotating armature; in the second, a couple of series of poles set alternately round a circumference or crown, the coils which rotate being set upon a frame between 2 such crowns of poles.

Confining attention to the first class of machines, in practice their magnets differ widely in construction and design.

In very few of the existing patterns is much trouble taken to secure steady magnets, by making them long, heavy, and solid, or with very heavy pole-pieces. Repeatedly an unnecessary amount of wire has been wound upon field-magnets; and the usual excuse is that, with less wire, the machine does not work so well. If, however, it is found necessary to wind on so many coils upon the magnets as to bring these practically to saturation long before the machine is doing its maximum work, it is clear that either the iron is insufficient in quantity or it is deficient in quality. In the Bürgin machines, where cast-iron field-magnets are employed, the smaller magnetic susceptibility of this metal is made up for by employing a great weight of it. In Siemens's smaller dynamos, the amount of iron employed in the field-magnets would be quite insufficient if it were not of high quality; as it is, Prof. Thompson is of opinion that the mass of it (especially in the polar parts) might with advantage be increased. In some of the early machines of Wilde, and in Edison's well-known dynamos, long field-magnets, with heavy pole-pieces, are found. Edison's dynamos, indeed, are all remarkable in this feature; the pole-pieces and the yoke connecting the iron cores of the coils are made abnormally heavy. This is not more noticeable in the giant dynamos used at the Holborn Viaduct, than in the smaller machines used in isolated installations for 60 and for 15 lights.

The principle of shaping the magnets, so that their external form approximates to that of the magnetic curves of the lines of force, is to some extent carried out in such widely differing types of machine as the Gramme with "Jamin" magnet, the Jürgensen dynamo, and Thomson's "mousemill" dynamo. The 2 machines last named exhibit several curious contrasts. In the Jürgensen, the field-magnets have heavy pole-pieces; in the Thomson, are none; and in the Thomson, the iron core is thicker at the middle than at the ends. In both, are auxiliary internal electro-magnets, fixed within the rotating armature, to concentrate and augment the intensity of the field, according to the device patented by Elphinstone and Vincent. In the Thomson machine, the coils are heaped on more thickly at the middle of the field-magnets; in the Jürgensen, the coils are crowded up around the poles. Judging from a report on this machine by Professors Ayrton and Perry, the arrangement is not satisfactory in practice, as there are more coils than suffice to magnetize the magnets.

Another suggestion, indicated from theoretical considerations, was that of laminating the pole-pieces, to prevent the production in them of wasteful Foucault currents. But one machine has been designed in which this precaution is carried into effect. This is the disk-dynamo of Drs. Hopkinson and Muirhead, the field-magnets of which are made up of laminæ of iron, cast into a solid iron backing.

Another matter is the form to be given to pole-pieces, in order to produce the best effect. These present such singular divergence in practice as to suggest the thought that little importance has been attached to them. Yet upon the form and extent given to the pole-pieces depend the reduction of idle wire in the armature, the reduction of sparking at the commutator, and the avoidance of counter-electromotive forces in the armature. If the pole-pieces are badly shaped for their work, or approach one another too far round the armature, they may completely perturb the approximate uniformity of the field, and may cause the central portion of the field to be of much weaker intensity than the two lateral regions between the edges of the pole-pieces. When this is the case, the rotating coils are virtually moving in a double field, and it is even possible that, in consequence, the direction of the currents induced in the individual coils may be reversed 4 or 6 times as they make one rotation. In such a case, the distribution of potential round the separate bars of the commutator will be abnormal.

Armatures.—The armatures of dynamos of the first class may be roughly classified in 3 groups, according to the manner of arranging the coils; these are—

(1) Ring armatures, in which the coils are grouped upon a ring, whose principal axis of symmetry is its axis of rotation also.

(2) Drum armatures, in which the coils are wound longitudinally over the surface of a drum or cylinder.

(3) Pole armatures, having coils wound on separate poles, projecting radially all round the periphery of a disk or central hub.

To these will be added a fourth form, disk armatures, when dealing with dynamos of the second class.

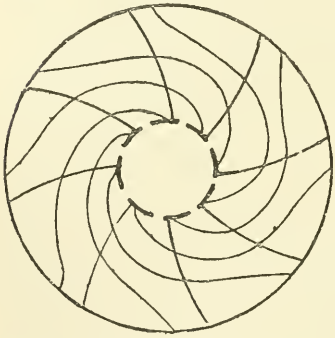
The object of all these combinations is to obtain practical continuity of current. Some of the individual coils should be moving through the position of maximum action, whilst others are passing the neutral point, and are temporarily idle. Hence a symmetrical arrangement around an axis is needed. Ring armatures are adopted in practice in the dynamos of Pacinotti, Gramme, Schückert, Gülcher, Fein, Heinrichs, De Meritens, Brush, Jürgensen, and others. Drum armatures are found in the Siemens (Alteneck), Edison, Elphinstone-Vincent, Laing, and other machines. Pole-armatures are used in the dynamos of Allen, Elmore, and of Lontin. There are several intermediate forms. The Bürgin armature consists of 8 or 10 rings, side by side, so as to form a drum. The Lontin (continuous-current dynamo) has the radial poles affixed upon the surface of a cylinder. The Maxim armature is a hollow drum wound like a Gramme ring, and has therefore a great quantity of idle wire on the inner surface of the drum. The Weston armature has the drum surface cut up into longitudinal poles; there is a similar armature by Jablochkoff, in which the poles are oblique.

Ring armatures are found in many machines, but the ingenuity of inventors has been exercised chiefly in 3 directions:—The securing of practical continuity; the avoidance of Foucault currents in the cores; and the reduction of useless resistance. In the greater part of these machines, the coils that form the sections of the ring are connected in series, the end of one to the beginning of the next, so that there is a continuous circuit all round, an attachment being made between each pair to a bar or segment of the collector. Most inventors have been content to secure approximate continuity by making the number of sections numerous. Prof. Perry has built up a ring with coils wound obliquely, so that the one coil reaches the neutral point before the preceding one has passed it; this arrangement presents mechanical difficulties in construction. Pacinotti's early dynamo had the coils wound between projecting teeth upon an iron ring. Gramme rejected these cogs, preferring that the coils should be wound round the entire surface of the endless core. To prevent wasteful currents in the cores, Gramme employed for that portion a coil of varnished iron wire of many turns. In Gülcher's latest dynamo, the ring-core is made up of thin flat rings cut out of sheet iron, furnished with projecting cogs, and laid upon one another. The parts of the coils which pass through the interior of the ring are comparatively idle. They cut very few lines of force as they rotate, and therefore offer a wasteful resistance. Inventors have essayed to reduce this source of loss, by either fitting projecting flanges to the pole-pieces (as in Fein's dynamo), or by using internal magnets (as in Jürgensen's), or by flattening the ring into a disk-form, so as to reduce the interior parts of the ring-coils to an insignificant amount. This is done in the dynamos of Schückert and Gülcher. In the latest form of Gülcher's dynamo, the field-magnets, at front and back of the ring, are united on the right and left sides in a pair of hollow pole-pieces, which form cases over the ring, covering a considerable part of it. The collector is identical with that of Gramme, but very substantial.

Drum-armatures may all be regarded

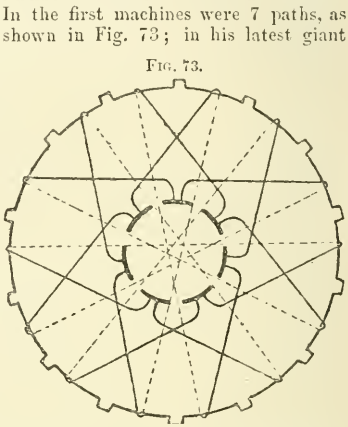
as modifications of Siemens's longitudinal shuttle-form armature of 1856, the multiplicity of sections of the coils affording practical continuity in the currents. In some of Siemens's machines, the cores are of wood, overspun with iron wire circumferentially, before receiving the longitudinal windings; in another, is a stationary iron core, outside which the hollow drum revolves; in others is no iron in the armature beyond the driving-spindle. In all the Siemens armatures, the individual coils occupy a diametral position with respect to the cylindrical core, but the mode of connecting up the separate diametral sections is not the same in all. In the older of the Alteneck-Siemens windings, the sections were not connected together symmetrically, but in more recent machines, a symmetrical plan has been adhered to, as shown in Fig. 72.

FIG. 72.



In this system, as in the Gramme ring, the successive sections of coils ranged round the armature are connected together continuously, the end of one section and the beginning of the next being united to one segment or bar of the collector. A symmetrical arrangement is of course preferable, not only for ease of construction, but because it is important that there should never be any great difference of potential between one segment of the collector and its next neighbour; otherwise there will be increased liability to spark, and form arcs across the intervening gap. In Edison's modification of the drum-armature, the winding, though symmetrical in one sense, is singular, inasmuch as the number of sections is an odd number. In the first machines were 7 paths, as shown in Fig. 73; in his latest giant

FIG. 73.



machines, the number of sections is 49. One consequence of this peculiarity of structure is that, if the brushes are set diametrically opposite to one another, they will not pass at the same instant from section to section of the collector; one of them will be short-circuiting one of the sections, whilst the other is at the middle of the opposite collector. The armature of the latest of Edison's dynamos is not wound up with wire, but, like some of Siemens's electro-plated dynamos, is constructed of solid bars of copper, arranged around the periphery of a drum. The ends are connected across by washers or disks of copper, insulated from each other, and having projecting lugs, to which the copper bars are attached. Such disks present much less resistance than mere strips would do. The connections are in the following order:—Each of the 49 bars of the collector is connected to a corresponding one of the 49 disks at the anterior end of the drum, which is connected, by a lug-piece on one side,

to one of the 98 copper bars. The current generated in this bar runs to the farther end of the machine, enters a disk at that end, crosses the disk, and returns along a bar diametrically opposite that along which it started. The anterior end of this bar is attached to a lug-piece of the next disk to that from which we began to trace the connections; it crosses this disk to the bar next but one to that first considered, and so round again. The 2 lug-pieces of the individual disks at the anterior end are therefore not exactly opposite each other, diametrically, as the connections advance through $\frac{1}{49}$ of the circumference at each of the 49 paths. The collector is very substantially built, and a screen is fixed between the collector and the rest of the armature, to prevent any copper-dust from flying back or clogging the insulation between the bars or disks. There are 5 pairs of brushes, the tendency to sparking being thereby greatly reduced. The core of the armature is made of very thin iron disks, separated by mica or asbestos paper from each other, and clamped together. Some exception may be taken to the use of such stout copper bars, as being more likely to heat from local currents than would be the case if bundles of straps or laminæ of copper were substituted. And, indeed, the presence of a 4 h.-p. fan to cool the armature is suggestive that continuous running is liable to heat it.

It is worth while to mention the peculiarity of form of the Bürgin armature, consisting of 8, or, in the newest machines constructed by Crompton, of 10 rings, set side by side. Each ring is made of a hexagonal coil of iron wire, mounted upon light metallic spokes, which meet the corners of the hexagon. Over this hexagonal frame, 6 coils of covered copper wire are wound, being thickest at the 6 points intermediate between the spokes, thus making up the form of each ring to nearly a circle. Each of the 6 coils is separated from its neighbour, and each of the 10 rings is fixed to the axis $\frac{1}{60}$ of the circumference in advance of its neighbour, so that the 60 separate coils are in fact arranged equidistantly (and symmetrically, as viewed from the end) around the axis. There is a 60-part collector, each bar of which is connected to the end of one coil and to the beginning of the coil that is $\frac{1}{10}$ in advance; that is, to the corresponding coil of the next ring. This armature has the great practical advantages of being easy in construction, light, and with plenty of ventilation.

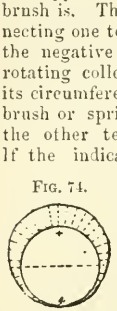
In the Elphinstone-Vincent dynamo is a drum-armature of a somewhat distinct order, the separate coils being made of a rectangular form, and then laid upon the sides of a hollow papier-maché drum in an overlapping manner, and curved to fit it. The field is complex, with 6 external and 6 internal poles, and is very intense, owing to the proximity of these poles. The parallelogram-shaped coils are connected together so as to work as 3 machines, and feed 3 pairs of brushes; which may again be united, either in series or in parallel, or may be used to feed 3 separate circuits.

Collectors.—On p. 123 the main points to be observed in the construction of collectors are enumerated. Collectors of such a type are common to all dynamos of the first class, except the Brush, in which there is a multiple commutator, instead of a collector. The collector of Pacinotti's early machine differed only in having the separate bars alternately a little displaced longitudinally along the cylinder, but still so that the same brush could slip from bar to bar. Niaudet's modification, in which the bars are radially attached to a disk, is a mere variety in detail, and is not justified by successful adoption. In the collector used in Weston's dynamo, and in some forms of Schückert's, the bars are oblique or curved, without any other effect than that of prolonging the moment during which the brush, while slipping from contact with one bar to contact with the next, short-circuits one section of the coil.

In a well-arranged dynamo of the first class, the sections of the collector are traversed by currents, which run

from the negative brush in 2 directions round the successive coils, and meet at that bar of the collector which touches the positive brush. Each section of the coil thus traversed adds its own electromotive force to the current passing through it. Consequently, on measuring the difference of potential between the negative brush and the successive bars of the collector, it is seen that the potential increases regularly all the way round the collecting cylinder, in both directions, becoming a maximum at the opposite side where the positive brush is. This can be verified by connecting one terminal of a voltmeter to the negative brush, and touching the rotating collector at different points of its circumference with a small metallic brush or spring attached by a wire to the other terminal of the voltmeter. If the indications thus obtained are plotted out round a circle corresponding to the circumference of the collector, the values give a curve like that shown in Fig. 74, from observations upon a Gramme dynamo.

FIG. 74.



It can be seen that, taking the negative brush as the lowest point of the circle, the potential rises regularly to a maximum at the positive brush. The same values are also plotted out as ordinates upon a horizontal line in Fig. 75. This form of diagram shows very

FIG 75.

clearly that the rise of potential is not equal between each pair of bars, otherwise the curve would consist merely of 2 oblique straight lines, sloping right and left from the central point. On the contrary, there is very little difference of potential between the collector bars close to the + brush on its right and left respectively. The greatest difference of potential occurs where the curve is steepest, at a position nearly 93° from the brushes; in fact, at that part of the circumference of the collector which is in connection with the coils that are passing through the position of best action. Were the field perfectly uniform, the number of lines of force that pass through a coil ought to be proportional to the sine of the angle which the plane of that coil makes with the resultant direction of the lines of force in the field, and the rate of cutting the lines of force should be proportional to the cosine of this angle. Now, the cosine is a maximum when this angle = 0°; hence, when the coil is parallel to the lines of force, or at 90° from the brushes, the rate of increase of potential should be at its greatest—as is very nearly realized in the diagram of Fig. 73, which, indeed, is very nearly a true "sinusoidal" curve. Such curves, plotted out from measurements of the distribution of potential at the collector, show not only where to place the brushes to get the best effect, but enable us to judge of the relative "idleness" or "activity" of coils in different parts of the field, and to gauge their actual intensity while the machine is running. If the brushes are badly set, or if the pole-pieces are not judiciously shaped, the rise of potential will be irregular, and there will be maxima and minima of potential at other points. An actual diagram, taken from a dynamo in which these arrangements were faulty, is shown in Fig. 76, and plotted horizontally in Fig. 77; from these it will be seen, not only that the rise of potential was irregular, but that one part of the col-

FIG. 76.

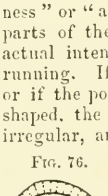
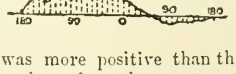


FIG. 77.



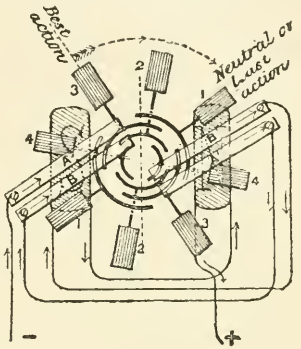
lector was more positive than the positive brush, and another part more negative than the negative. The brushes, therefore, were not getting their proper difference of potential; and in part of

the coils the currents were actually being forced against an opposing electromotive force. In a badly-arranged dynamo giving such a diagram as Fig. 76, a second pair of brushes, applied at the points, showing maximum and minimum potential, could draw a good current without interfering greatly with the current flowing through the existing brushes.

Curves similar to those given can be obtained from the collectors of any dynamo of the first class—Gramme, Siemens, Edison, &c.—saving only from the Brush machine, which, having no such collector, gives diagrams of a different kind. It is not needful, in taking such diagrams, that the actual brushes of the machine should be in contact, or that there should be any circuit between them, though in such cases the field-magnets must be separately excited. Also, the presence of brushes, drawing a current at any point of the collector, will alter the distribution of potential in the collector; and the manner and amount of such alteration will depend on the position of the brushes, and the resistance of the circuit between them.

Brush Dynamo. — Its armature — a ring in form, not entirely overwound with coils, but having projecting teeth between the coils like the Pacinotti ring—is unique. Though it resembles Pacinotti's ring, it differs more from the Pacinotti armature than that differs from those of Siemens, Gramme, Edison, Bürgin, &c.; for in all those, the successive sections are united in series all the way round, and constitute, in one sense, a continuous bobbin. But in the Brush armature is no such continuity. The coils are connected in pairs, each to that diametrically opposite it, and carefully isolated from those adjacent to them. For each pair of coils is a separate commutator, so that for the ordinary ring of 8 coils are 4 distinct commutators side by side upon the axis—one for each pair of coils. The brushes are arranged so as to touch at the same time the commutators of 2 pairs of coils, but never of 2 adjacent pairs; the adjacent commutators being always connected to 2 pairs of coils that lie at right angles to one another in the ring. The arrangement is given in Fig. 78.

FIG. 78.



In this figure, the 8 coils are numbered as 4 pairs, and each pair has its own commutator, to which pass the outer ends of the wire of each coil, the inner ends of the 2 coils being united across to each other (not shown). In the actual machine, each pair of coils, as it passes through the position of least action (*i.e.*, when its plane is at right angles to the direction of the lines of force in the field, and when the number of lines of force passing through it is a *maximum*, and the rate of change of these lines of force a *minimum*) is cut out of connexion. This is accomplished by causing the 2 halves of the commutator to be separated from one another by about $\frac{1}{8}$ of the circumference at each side. In the figure, the coils marked 1, 1, are "cut out." Neither of the 2 halves of the commutator touches the brushes. In this position, however, the coils 3, at right angles to 1, are in the position of best action, and the current powerfully induced in them flows out of the brush A (which is therefore the negative brush) into A'. This brush is connected across to brush B, where the current re-enters the armature. Now, the coils 2 have just left the position of best action, and the coils 4 are beginning to approach that position.

Through both these pairs of coils, therefore, a partial induction will be going on. Accordingly, it is arranged that the current on passing into B, splits, part going through coils 2 and part through 4, and re-uniting at the brush B', whence the current flows round the coils of the field magnets to excite them, and then round the external circuit, and back to the brush A. (In some machines it is arranged that the current shall go round the field-magnets after leaving brush A', and before entering brush B; in which case the action of the machine is sometimes, though not correctly, described as causing its coils, as they rotate, to feed the field-magnets and the external circuit alternately.) The rotation of the armature will then bring coils 2 into the position of least action, when they will be cut out, and the same action is renewed with only a slight change in the order of operation. The following table summarizes the successive order of connexions during a half-revolution :—

First position. (Coils 1 cut out.)

$$A-3-A';\ B < {}^{4}_{2} > B';$$

Field-magnets—External circuit—A.

Second position. (Coils 2 cut out.)

$$A < {}^{1}_{3} > A';\ B-4-B';$$

Field-magnets—External circuit—A.

Third position. (Coils 3 cut out.)

$$A-1-A';\ B < {}^{2}_{4} > B';$$

Field-magnets—External circuit—A.

Fourth position. (Coils 4 cut out.)

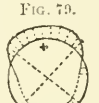
$$A < {}^{3}_{1} > A';\ B-2-B';$$

Field-magnets—External circuit—A.

Whichever pair of coils is in the position of best action is delivering its current direct into the circuit; whilst the 2 pairs of coils which occupy the secondary positions are always joined in parallel, the same pair of brushes touching the respective commutators of both.

One consequence of the peculiar arrangement thus adopted is, that measuring the potentials round one of the commutators with a voltmeter, gives a wholly different result from that obtained with other machines. For $\frac{1}{8}$ of the circumference on either side of the positive brush, there is no sensible difference of potential. Then comes a region in which the potential appears to fall off; but the falling-off is here partly due to the shorter time during which the adjustable brush connected with the voltmeter and the fixed positive brush are both in contact with the same part of the commutator. Farther on is a region in which the voltmeter gives no indications corresponding to the cut-out position; and again, on each side of the negative brush, is a region where the polarity is the same as that of the negative brush. Fig. 79 is a diagram of a 6-

FIG. 79.



light Brush taken at one commutator, the main + brush being, however, allowed to rest (as in its usual position), in contact with both this commutator and the adjacent one.

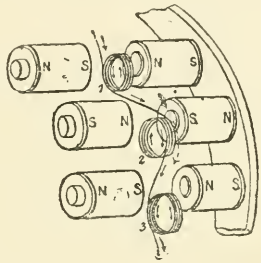
From the foregoing considerations, it is clear that the 4 pairs of coils of the Brush machine really constitute 4 separate machines, each delivering alternate currents to a commutator, which commutes them to intermittent uni-directional currents in the brushes; and that these independent machines are ingeniously united in pairs by the device of letting one pair of brushes press against the commutators of 2 pairs of coils. Further, that these paired machines are then connected in series by bringing a connection round from brush A' to brush B.

Dynamos of Second Class.—In these, coils are carried round to different parts of a magnetic field, whose intensity differs in different regions; or one, in different parts of which the lines of force run in opposite directions. In the early machine of Pixii, a single pair of coils was mounted so as to pass in this fashion through parts of the field where the magnetic induction was oppositely directed. Such a machine gives alternate currents, unless a commutator be affixed to the rotating axis. Niaudet's dynamo, which may be regarded as a compound Pixii machine, having the separate armature coils

united as those of Gramme and Siemens into one continuous circuit, is furnished with a radial collector mentioned above. In the Wallace-Farmer dynamo is a pair of poles at the top arranged so that the N. faces the S. pole, and another pair at the bottom where the S. faces the N. pole. The coils are carried round, their axis being always parallel to the axis of rotation upon a disk; there being 2 sets of coils on opposite faces of 2 iron disks set back to back. They are united precisely as in Niaudet's dynamo, and each disk has its own collector. Each bar of the collector is, moreover, connected, as in the Pacinotti, Gramme, Siemens, &c., with the end of one coil and the beginning of the next. In fact, the Wallace-Farmer is merely a double Niaudet with cylindrical collectors. There is a serious objection to the employment of solid iron disks such as these: in a very short time they grow hot from the eddying Foucault currents engendered in them as they rotate. This waste reduces the efficiency. In the Hopkinson and Muirhead dynamo, the disk-armature takes a more reasonable shape. Instead of a solid iron disk to support the coils, is a disk built up of a thin iron strip wound spirally round a wooden centre. The coils, of approximately quadrangular shape and flat form, are wound upon the sides of this compound disk. The Ball dynamo (so-called "Arago-disk") is similar in many respects, but has no iron cores to the armature coils.

Alternate-current Dynamos.—By far the most important of the dynamos of this second class are those usually known as "alternate-current machines." This type of dynamo was originally created by Wilde, in 1867. The field-magnets consist of 2 crowns of fixed coils, with iron cores, arranged so that their free poles are opposite one another, with a space between them sufficiently wide to admit the armature. The poles taken in order round each crown are alternately of N. and S. polarity, and opposite a N. pole of one crown faces a S. pole of the other. This applies to the magnets of the alternate-current machines of Wilde and Siemens, the Ferranti machine, and, with certain reservations, to the Lachaussée and the Gordon. The armatures in almost all machines of this type consist of a disk, bearing at its periphery a number of coils, whose axes are parallel to the axis of rotation. The principle is shown in Fig. 80,

FIG. 80.



which gives a general view of the arrangement. Since the lines of force run in opposite directions between the fixed coils, which are alternately S.—N., N.—S., the moving coils will be traversed by alternating currents; and as the alternate coils of the armature will be traversed by currents in opposite senses, it is needful to connect them up so that they shall not oppose one another's action.

In Wilde's dynamo, the armature coils have iron cores, and the machine is provided with a commutator on the same principle as that used by Jacobi in his motor of 1838, consisting of 2 metallic cylinders, cut like crown wheels, having the teeth of one projecting between those of the other, so that the brushes make contact against them alternately as they rotate. The brushes are fixed so that they do not both touch the same part. This commutator Wilde usually applied to a few, or only one, of the rotating coils, and utilized the current thus obtained to magnetize the field-magnets. The main current was not so commuted, but was led away from a simple collector, consisting of 2 rings connected to the 2 ends of the armature circuit, each being pressed by one brush.

Siemens prefers to use a separate

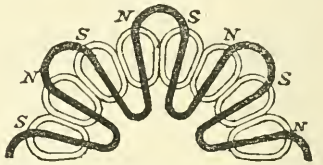
direct current machine to excite the field-magnets of alternate-current dynamos. In the armature of the latter, the coils are wound, usually without iron, upon wooden cores. In some forms of the machine, the individual coils are enclosed between perforated disks of thin German silver. When currents of great strength are required, but not of great electromotive force, the coils are coupled up in parallel arc, instead of being united in series.

In a dynamo by Lachaussée, which very strikingly resembles the preceding one, there is iron in the cores of the rotating coils. But the main difference is that the rotating coils are the field-magnets, excited by a separate Gramme dynamo, whilst the coils, which are fixed in 2 crowns on either side, act as armature coils in which currents are induced.

Gordon's dynamo is constructed on the same lines as the Lachaussée, but with many important improvements. In the first place, there are twice as many coils in the fixed armatures as in the rotating magnets, there being 32 on each side of the rotating disk, or, in all, 64 moving coils; while there are 64 on each of the fixed circles, or 128 stationary coils in all. The latter are of an elongated shape, wound upon a bit of iron boiler-plate, bent up to an acute V form, with cheeks of perforated German silver as flanges. The object of thus arranging the coils, so that the moving ones shall have twice the angular breadth of the fixed ones, is to prevent adjacent coils of the fixed series from acting detrimentally, by induction, upon one another. The alternate coils of the fixed series are united together in parallel arcs, so that there are 2 distinct circuits, in either or both of which lamps can be placed; or they can be coupled up together. Great care appears to have been taken, in the construction of this large machine, to guard against the appearance of Foucault currents, by arranging the cores, frames, and coils, so that all metallic parts of any size shall be slit, or otherwise structurally divided at right angles to the direction of the induced electromotive forces.

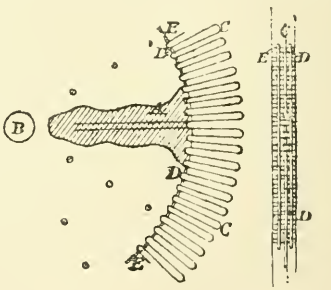
Another alternate-current dynamo, identical in many respects with the Siemens, is the Ferranti. As in the machines of Wilde and Siemens, the electro-magnets form 2 crowns with opposing poles. The point of difference is the armature, which, like that of Siemens, has no iron cores in its coils; but which, unlike that of Siemens, is not made up of coils wound round cores, but consists of zigzags of strip copper folded upon one another. There are 8 loops in the zigzag (as shown in Fig. 81), which

FIG. 81.



depicts half only of the arrangement, and on each side are 16 magnet poles; so that, as in Gordon's dynamo, the moving parts are twice the angular breadth of the fixed parts. The advantage of the armature of zigzag copper lies in its simplicity of construction. Sir W. Thomson, who is the real inventor of this armature, proposed originally that the copper strips should be wound between projecting teeth on a wooden wheel, as indicated in Fig 82. He also

FIG. 82.



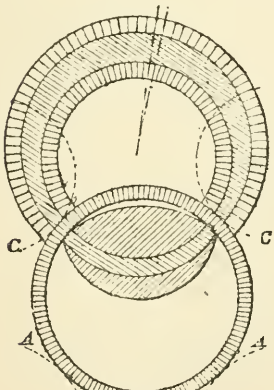
proposed to use as field-magnets a form of electro-magnet of the kind known as Roberts's, also used by Joule, in which

the wires that bring the exciting current are passed up and down, in a zigzag form, between iron blocks projecting from an iron frame.

Prof. Thompson is not at all convinced that this type of machine, though at present fashionable, is destined to prove of very great value, because he doubts whether any dynamo that yields alternate currents can compete with continuous-current machines. For the purposes of a general system of distribution, where more than one dynamo must be available, and for the purpose of supplying motors, alternate-current machines are quite out of the question. Besides the disk armatures described, pole armatures have been employed in alternate-current machines by Gramme, Jablochkoff, and Lontin. Hefner Alteneck has gone a stage farther, and, by the device of employing a disk armature in which the number of coils differed by 2, or some other even number, from those of the field, and by the employment of a multiple-bar collector with complicated cross connections, has succeeded in converting this type of dynamo into a continuous-current machine.

Thomson's "Mouse-mill."—This dynamo is shown in Fig. 83 in diagram. The armature is a hollow cylinder s,

FIG. 83.



made up of parallel copper bars, arranged like the bars of a mouse-mill (whence the name of the machine). These bars are insulated from each other, but are connected all together at one end. At the other, they serve as collector-bars, and deliver up the currents generated in them to the "brushes," which here are rotating disks of springy copper shown as dotted circles at C. As the armature is a hollow barrel, with fixed electro-magnets within, it cannot be rotated on a spindle, but runs on friction rollers AA', by one or more of which it is driven.

Dynamos of Third Class.—The earliest machine which has any right to be called a dynamo was of this class. Barlow and Sturgeon had shown that a copper disk, placed between the poles of a magnet, rotates in the magnetic field when traversed by an electric current from its axis to its periphery, where there is a sliding contact. Faraday, in 1831, showed that by rotating a similar disk mechanically between the poles of a magnet, continuous currents were obtained. These he drew off by collecting springs of copper or lead, one of which touched the axis whilst the other pressed against the amalgamated periphery. Here was demonstrated the production of a permanent (*i.e.* continuous) current of electricity by ordinary magnets. He went on to employ the principle of separate excitement of his field-magnets. Effects were obtained from *electro-magnetic poles*, resulting from the use of copper helices or spirals, either alone or with iron cores. The directions of the motions were precisely the same; but the action was much greater when the iron cores were used than without. Such a machine as Faraday's is impracticable for several reasons: the peripheral friction is inadmissible on any but a small scale; and the disposition of the field-magnets necessarily evokes wasteful eddy-currents in the disk, which, even if slit radially, would not be an appropriate form of armature for such a limited magnetic field.

Another method of obtaining a continuous cutting of the lines of force, is

where a sliding conductor travels round the pole of a magnet. Faraday even generated continuous currents by rotating a magnet with a sliding connection at its centre, from which a conductor ran round outside, and made contact with the end-pivots which supported the magnet.

A similar arrangement was devised by Varley about 1862. He rotated an iron magnet in a vertical frame, having a mercurial connection at the centre. The current which flowed from both ends of the magnet toward the centre was made to return to the machine, and to pass through coils surrounding the poles of the rotating magnet; thus anticipating the self-exciting principle of later date. Varley also proposed to use an external electro-magnet to increase the action.

Quite recently, the same fundamental idea has been worked upon by Siemens and Halske, who have produced a so-called "unipolar" machine. In this remarkable dynamo are 2 copper cylinders, both slit longitudinally to obviate eddy-currents, each of which rotates round one pole of a U-shaped electro-magnet. A second electro-magnet, placed between the rotating cylinders, has protruding pole-pieces of arching form, which embrace the cylinders above and below. Each cylinder, therefore, rotates between an internal and external pole of opposite polarity, and consequently cuts the lines of force continuously by sliding upon the internal pole. The currents from this machine are of very great strength, but of only a few volts of electromotive force. To keep down the resistance, many collecting brushes press on each end of each cylinder. This dynamo is actually at work for electro-plating.

In Voice's dynamo, a coil armature, wound upon an iron ring, is so placed that the iron ring is itself one pole of a magnet, a projecting pole-piece from the other pole being fixed near it, so that the coils fixed upon one pole glide round and cut the lines of force proceeding from the other pole. Whether this machine will be a practical one remains to be seen.

Fire Risks.—The following rules and regulations are drawn up by a committee of the Society of Telegraph Engineers and Electricians for the reduction to a minimum, in the case of electric lighting, of those risks of fire which are inherent in every system of artificial illumination, and also for the guidance and instruction of those who have, or who contemplate having, electric lighting apparatus installed in their premises. The difficulties that beset the electrical engineer are chiefly internal and invisible, and they can only be effectually guarded against by "testing," or probing with electric currents. They depend chiefly on leakage, undue resistance in the conductor, and bad joints, which lead to waste of energy and the dangerous production of heat. These defects can only be detected by measuring, by means of special apparatus, the currents that are, either ordinarily or for the purpose of testing, passed through the circuit. Should wires become perceptibly warmed by the ordinary current, it is an indication that they are too small for the work they have to do, and that they should be replaced by larger wires. Bare or exposed conductors should always be within visual inspection, and as far out of reach as possible, since the accidental falling on to, or the thoughtless placing of other conducting bodies upon, such conductors, would lead to "short circuiting," and the consequent sudden generation of heat due to an increased current in conductors not adapted to carry it with safety.

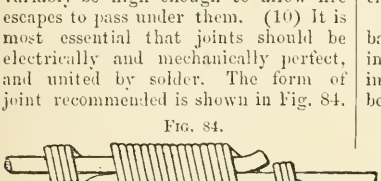
The necessity cannot be too strongly urged for guarding against the presence of moisture and the use of "earth" as part of the circuit. Moisture leads to loss of current and to the destruction of the conductor by electrolytic corrosion, and the injudicious use of "earth" as a part of the circuit tends to magnify every other source of difficulty and danger. The chief dangers of every new application of electricity arise from ignorance and inexperience on the part of those who supply and fit up the requisite plant. The greatest element of

safety is therefore the employment of skilled and experienced electricians to supervise the work.

(*a*) *The Dynamo Machine.*—(1) The dynamo machine should be fixed in a dry place. (2) It should not be exposed to dust or flyings. (3) It should be kept perfectly clean and its bearings well oiled. (4) The insulation of its coils and conductors should be practically perfect. (5) All conductors in the dynamo room should be firmly supported, well insulated, conveniently arranged for inspection, and marked or numbered.

(*b*) *The Wires.*—(6) Every switch or commutator used for turning the current on or off should be constructed so that when it is moved and left it cannot permit of a permanent arc or of heating. (7) Every part of the circuit should be so determined that the gauge of wire to be used is properly proportioned to the currents it will have to carry, and all junctions with a smaller conductor should be fitted with a suitable safety fuse or protector, so that no portion of the conductor should ever be allowed to attain a temperature exceeding 150° F. (65½° C.). (8) Under ordinary circumstances, complete metallic circuits should be used; the employment of gas or water pipes as conductors for the purpose of completing the circuit should not in any case be allowed. (9) Bare wires passing over the tops of houses should never be less than 7 ft. clear of any part of the roof, and all wires crossing thoroughfares should invariably be high enough to allow fire escapes to pass under them. (10) It is most essential that joints should be electrically and mechanically perfect, and united by solder. The form of joint recommended is shown in Fig. 84.

FIG. 84.



(11) The position of wires when underground should be clearly indicated, and they should be laid down so as to be easily inspected and repaired. (12) All wires used for indoor purposes should be efficiently insulated, either by being covered throughout with some insulating medium, or, if bare, by resting on insulated supports. (13) When these wires pass through roofs, floors, walls, or partitions, or where they cross or are liable to touch metallic masses, like iron girders or pipes, they should be thoroughly protected by suitable additional covering; and where they are liable to abrasion from any cause, or to the depredations of rats or mice, they should be efficiently encased in some hard material. (14) Where indoor wires are put out of sight, as beneath flooring, they should be thoroughly protected from mechanical injury, and their position should be indicated. N.B.—The value of frequently testing the apparatus and circuits cannot be too strongly urged. The escape of electricity cannot be detected by the sense of smell, as can gas, but it can be detected by apparatus far more certain and delicate. Leakage not only means waste, but in the presence of moisture it means destruction of the conductor and its insulating covering, by electric action.

(*c*) *Lamps.*—(15) Arc lamps should always be guarded by proper lanterns to prevent danger from falling incandescent pieces of carbon, and from ascending sparks. Their globes should be protected with wire netting. (16) The lanterns, and all parts which are to be handled, should be insulated from the circuit.

(*d*) *Danger to Person.*—(17) Where bare wire out of doors rests on insulating supports, it should be coated with insulating material, such as indiarubber tape or tube, for at least 2 ft. on each side of the support. (18) To secure persons from danger inside buildings, it is essential so to arrange and protect the conductors and fittings, that no one can be exposed to the shocks of alternating currents of a mean electromotive force exceeding 100 volts, or to continuous currents of 200 volts. (19) If the differ-

ence of potential within any house exceeds 200 volts, the house should be provided with a "switch," so arranged that the supply of electricity can be at once cut off.

With reference to par. (10), Bolas says that the best way to make an electrical joint is, first to thoroughly tin the wires, and then wipe them carefully while they are still hot; any chloride of zinc which may have been used being next removed by a damp cloth. The wires are then bound, and subsequently well grouted with solder, rosin only being used as a flux.

Killingworth Hedges, in a paper recently read before the British Association, alludes to some sources of danger not previously mentioned. Thus, in reference to the development of heat caused by an increased resistance, he recalls Matthiessen's experiment showing that the conducting power of "commercial" copper wire is only 13·6 as against 99·95 for pure copper: hence the wire used must be pure throughout. An absolute essential is a cut-out or fusible plug in the circuit, arranged to melt if the current is more than 10 to 15 per cent. in excess of the working strength.

Measuring.—The following observations on the measurement of electric currents are condensed from J. N. Shoolbred's paper on the "Measurement of Electricity" ('Jl. Soc. Arts,' Ap. 6, 1883), and one by Professors Ayrton and Perry on "Measuring Instruments used in Electric Lighting and Transmission of Power."

The measurement of all physical quantities rests upon 3 fundamental units—length, mass, and time. All others can be deduced from these. The fundamental units chosen for electrical measuring are: length, 1 centimetre; mass, 1 gramme; time, 1 second; and the term "C.G.S." was applied to the whole system.

As, with the use of a scale common to all quantities, both very large and very small numbers must often be represented, it is advocated in the C.G.S. system to express each number as the product of 2 factors, 1 of them being a power of 10; also to effect this in such a way that the exponent of the power of 10 shall be the characteristic of the logarithm of the number. Thus, 1,280,000 would be written as $1{\cdot}28\times10^6$, and ·000128 as $1{\cdot}28\times10^{-4}$.

The following table contains some of the units based upon the C.G.S. system:—

C.G.S. UNITS OF MEASUREMENT.

Fundamental Units.

Length, 1 centimetre; mass, 1 gramme; time, 1 second.

Derived Units.—Mechanical.

Velocity.—Unit length in unit time $\frac{\text{Centimetre}}{\text{Second.}}$

Acceleration.—Rate of increase of velocity per second: In gravitation measure $= g$. g, in latitude of London = 981 C.G.S. units.

Momentum.—Momentum of 1 gramme with a velocity of 1 centimetre per second.

Force or Power—*Dyne.*—Force which, acting upon 1 gramme for a second, generates a velocity of 1 centimetre per second.

Work—*Erg.*—Amount of work done by 1 dyne working through 1 centimetre of distance.

Electro-magnetic.

Magnetic Pole.—A pole which, at 1 centimetre distance from a similar pole, gives a force of 1 dyne.

Magnetic Field.—The intensity of a field which acts on unit magnetic pole with a force of 1 dyne.

Current.—A current flowing along 1 centimetre of a circuit in form of a circular arc, of 1 centimetre radius; and exerting a force of 1 dyne on a unit pole placed at the centre.

Quantity.—The quantity conveyed by unit current in 1 second.

Potential or Electromotive Force.—The difference of the electric condition between 2 conductors, or 2 points of a conductor, when the trans-

ference of electricity from one to the other is proceeding at the rate of 1 erg of work per unit of electricity transferred.

Resistance.—A resistance such that, with unit of difference of potential between the ends of conductor, 1 unit of current is conveyed along it.

N.B.—The estimation of resistance actually resolves itself into a question of velocity, *i.e.* $\frac{\text{Length}}{\text{Time}}$

Some of the above C. G. S. electromagnetic units being found to be inconveniently large, and others to be far too small, the following "practical" units, for general use, have been deduced from them, and are now being universally adopted.

"Practical" Electrical Units.

The *ohm* (10^9 C. G. S. units of resistance), as the unit of resistance, is that of a column of mercury having 1 sq. millimetre of section, and of a length hereafter to be determined by a commission specially appointed for the purpose. *Note.*—The length is supposed, however, to be between 104 and 105 centimetres.

The *volt* (10^8 C. G. S. units of electromotive force), as the unit of electromotive force. *Note.*—This corresponds nearly to that of a Daniell's cell.

The *ampère* (10^{-1} C. G. S. units of current), as the unit of current; which is the current produced by 1 volt through 1 ohm.

The *coulomb* (10^{-1} C. G. S. units of quantity), as the unit of quantity of electricity; which is defined by the condition that an ampère yields 1 coulomb per second.

The *farad* (10^{-9} C. G. S. units of capacity), as the unit of capacity; which is such that 1 coulomb in a farad shall give 1 volt.

Or, to quote the words of Sir Wm. Thomson, "The volt acting through an ohm gives a current of 1 ampère, that is to say, 1 coulomb per second; and the farad is the capacity of a condenser, which holds 1 coulomb, when the difference of potential of its 2 plates is 1 volt."

The following was suggested by Dr. C. W. Siemens to be added to the above units:—

The *watt* (10^7 C. G. S. units of power), as the unit of power: being the power conveyed by a current of 1 ampère in 1 second through a conductor whose ends differ in potential by 1 volt.

The *joule* (10^7 C. G. S. units of work), as the unit of work, or heat, being the heat generated by a watt in a second.

In the construction of instruments for the generation and measurement of electric currents, great advantage is taken of the inducting action of magnets upon coils; of the effect of the passage of the electric current through a coil upon a magnetic needle in its vicinity; and of the result of electric currents of different intensities upon each other, in their passage through conductors in the form of coils.

The evaluation of the electrical energy of a supply depends upon the exact measurement of 2 factors—the amount of the supply and the pressure under which it is given; or the quantity of the current and the electromotive force. The product of the current expended, in ampère seconds, or of this amount of quantity expressed in coulombs, by the electrical pressure of the same, expressed in volts, gives the electrical energy expended, or the power of the supply. The electrical energy is therefore represented by the product of volts × ampères × time; or by the product of volts × coulombs; or, expressed algebraically, $W = ECt = EQ$.

Following are equivalent expressions for the same amount of power, expressed in other terms, some of which may be more familiar:—

Rate of expending Energy.

1 volt-ampère = $\begin{cases} 10^7 \text{ ergs per second.} \\ 1 \text{ watt.} \\ 7 \cdot \frac{3}{7} \text{ foot-pounds per second.} \\ 5 \cdot \frac{1}{37} \text{ kilogrammetres per second.} \\ \frac{1}{736} \text{ force-cheval (French horse-power).} \\ \frac{1}{746} \text{ horse-power.} \end{cases}$

The Board of Trade suggest that the unit of price to be charged should be based on "the energy contained in a current of 1000 ampères flowing under an electromotive force of 1 volt during 1 hour;" or, in other words, the unit might be put as 1000 volt-ampère hours. The ampère hour is another way of saying 3600 coulombs of quantity of electricity supplied. It may be of interest to state in other more conventional terms the equivalent of the amount of work implied in the above unit:—

Work done, or Energy expended.

1000 volt-ampère hours =
- 10^{10} erg hours.
- 3,600,000 volt-coulombs.
- 3,600,000 joules.
- 1000 watt-hours.
- 2,645,000 foot-pounds.
- 366,840 kilogrammetres.
- 1·35 force-cheval heures.
- 1·34 horse-power hours.

Put in terms more in accordance with actual practice, the above unit might mean the supply for 1 hour of a current of 10 ampères with an electromotive force of 100 volts; or a 5-ampère current with an E. M. F. of 200 volts; or a 10-ampère current at 200 volts for only ½ hour; and so on, provided that the product of the 3 factors is always 1000.

To arrive at an evaluation of the supply of electric energy, the measurement of each of these 2 factors (in volts and ampères respectively), must be effected either separately or combined, and a continuous and cumulative record must be kept of the supply as it proceeds. To measure with completeness, for commercial purposes, a supply of electricity, entails a continuous record of current and pressure, either separately or combined. In the supply of towns, the question for the consumer will probably be much simplified by causing one element, pressure, to remain constant. If so, it becomes the duty of suppliers to keep up that pressure under penalty; and instruments for recording such pressure will have to be installed where required, and placed under proper supervision. For the customer, it will then generally suffice to have an exact record of the quantity of his individual consumption of electric supply.

Some of the non-recording instruments in more general use, by the addition of recording apparatus, by which the element of time can be integrated, may be made into registering meters. Thus, any current or ampère measurer may be converted into a record of quantity; or a coulomb-meter, by the integration of the time during which the current has flowed; and, similarly, any power or volt-ampère measurer may become a register of work done by means of the addition of the elements of time. Again, volt or pressure measurers will always be required in any case where a check is needed upon the actual difference of potential or electromotive force of the supply; and this may arise from a variety of causes.

NON-REGISTERING INSTRUMENTS.—(*a*) *Current Measurers.*—(1) Siemens's Electro-dynamometer consists of a fixed coil, and of a movable coil suspended by a thread and a spiral spring, the normal position of the latter being at right angles to that of the former. When a current is sent through the 2 coils in series, the movable coil is deflected; this deflection is counteracted by torsion of the spiral spring, the amount of such torsion (indicated by a pointer on an index-dial) being proportioned to the square of the current strength.

(2) Obach's Tangent Galvanometer has a movable ring round a horizontal axis. If the ring is vertical, the needle tends to turn on a vertical axis, as in the ordinary tangent galvanometer (the opposing force being the horizontal component of the earth's magnetism); if, however, the ring is placed horizontally, the needle turns round a horizontal axis, or dips (the opposing force being the vertical component of the earth's magnetism). The effect of the intensity of the current upon the needle may therefore be varied with the inclination of the ring. With the ring in

any fixed position, the current strength is proportional to the tangent of the deflection (as in an ordinary tangent galvanometer).

(3) Cardew's Low-resistance Galvanometer is based on the principle of finding the intensity of an unknown current by balancing it against one of known strength, and thus ascertaining the relation between the two. It consists of 2 coils, a thick wire one (for the unknown current), and a thin wire one (for the standard one); both are wound on the same bobbin, but are insulated from each other. A magnet, with needle-pointer, is pivoted in the centre of the bobbin, and its deflections are counteracted by the insertion of known resistance.

(4) Ayrton and Perry's Am-meter.—This instrument is made in several forms. In its original shape, it consists of a permanent magnet of horse-shoe pattern, with a needle-armature fixed between its pole-pieces. These are made of such a shape as to ensure that the deflections of the needle shall be directly proportional to the intensity of the current causing them; hence a knowledge only of the constant of each instrument is required when using it. Furthermore, the coil of wire through which the current passes, is in some instruments divided up into 10 strands, which may, by means of a cylindrical commutator, be coupled up in "parallel" or in "series," as it is desired or not to magnify the deflection 10-fold for small currents. In cases where loss of magnetism in the permanent magnet is to be feared, a spiral spring is made to take the place of the horse-shoe magnet as the controlling force. Again, where extreme delicacy is required, the deflections of the needle may be magnified 10-fold or more, by attaching to the shaft of the needle a wheel and pinion. This form of instrument is adapted for use with strong currents.

(5) Deprez's Galvanometer consists of a horse-shoe permanent magnet, with a solid armature-needle of peculiar "fish-bone" form, and index-pointer, pivoted vertically, placed between its poles, and a coil of the wire, which carries the current to be measured, laid within the horse-shoe. A table indicating the value of the several deflections of the needle has to be used.

(6) Thomson's Current Galvanometer.—This instrument, together with its fellow one, for the measurement of the difference of potential, have been termed "graded galvanometers." They are designed to permit of a very wide range being obtained with each respectively; this being effected by varying the intensity of the magnetic field in a known ratio, and comparing with it the unknown current. The present instrument consists essentially of 2 parts; a coil of thick wire, through which the current to be measured is allowed to pass, it being fixed upright at the end of a wooden platform, with about $\frac{1}{2}$ only of the coil projecting above it; and a "magnetometer." This last consists of 4 short steel magnets (constituting the "needle") mounted in a frame on a vertical axis, with a long aluminium pointer attached, and enclosed in a quadrant-shaped box, with a glass cover and a silvered glass mirror bottom (in order to counteract any effect of parallax while reading the scale of tangents, to which the instrument is graduated). To increase the directive force of the needle, when required, a semicircular permanent magnet of hard steel, and of known intensity, may be fixed upright on 2 arms projecting from the magnetometer, behind the apex of the quadrant. The magnet stands over the needle, with its magnetic axis in the horizontal plane through that of the needle. The magnetometer is made to slide along a groove in the wooden platform in front of the fixed coil, and in a direction at right angles to it, the axis of the magnet and of the needle (when at rest) being parallel to that of the coil; while the aluminium pointer, when at zero, which is the centre of the scale, lies in the same direction as the groove, or at right angles to the coil. The range of sensibility obtained by varying the extreme distance along the groove of the magnetometer from the coil is about

50-fold; while by removing the magnet, and leaving the needle under the influence of the earth's force alone, a further sensibility 50 times greater can be obtained.

(*b*) *Pressure Measurers.*—(1) Ayrton and Perry's Volt-meter is in principle and form like their am-meter, and has, like it, several similar modifications. The essential difference between the 2 instruments is that the thick wire coil of the am-meter is here replaced by a thin wire coil, with the connections to its ends so arranged as to measure the difference of potential between the points desired.

(2) Thomson's Potential Galvanometer differs only from his "current" instrument, already described, in the use of a thin wire coil (of German silver of about 6000 ohms resistance), instead of a thick wire coil; and in the change in the connections to suit the present object.

(3) Siemens's Torsion Galvanometer consists of a bell-magnet suspended between 2 coils of fine wire by means of a thread and a spiral spring. The deflections of the magnet under the current are counteracted by means of the spring, as in the electro-dynamometer, only that the angles of torsion are here proportional simply to the intensity. Certain resistances can also be added by which the sensitiveness can, by means of the insertion of a plug, be increased 10-fold.

(*c*) *Power or Energy Measurers.*—(1) Ayrton and Perry's Power-meter consists of a thick wire coil through which the main current passes, and of a fine wire coil on a shunt, which is suspended within it. The axes of the 2 coils are parallel, and the passage of a current tends to deflect the suspended one. Since the thick wire coil measures the intensity of the current, and the thin wire one its electromotive force, and as the deflection of the latter is the product of the two, therefore the amount of that deflection is the measure of the power, or energy, of the current. Modifications of this instrument, with or without a commutator, or with a wheel and pinion arrangement, are also made.

(2) Siemens's Watt-meter is constructed on the same principle as the electro-dynamometer. The 2 coils are, however, kept distinct, with separate terminals to each. The fixed one, of thin wire on a shunt, measures the electromotive force; while the movable one has the main current passing through it. The resulting position of the latter coil is due directly to the intensities of the 2 currents; that is, to the power developed. This product, of volts × ampères, is watts; hence the name of the instrument. The angle of torsion of the index-pointer gives the watts directly, and with the knowledge of the particular constant.

(*d*) *Resistance Measurers.*—Measurements of this class are generally carried out by means of a galvanometer, a set of resistance coils, and a Wheatstone bridge (therewith balancing the unknown resistance by means of one of a known amount).

Ayrton and Perry's Ohm-meter consists of 2 coils: a thick wire one for the main current, and a thin wire one on a shunt for the electromotive force. Both are fixed with their axes at right angles to each other. A needle is acted upon by the currents flowing through each, and as these are at right angles to each other, the resulting deflection represents the ratio $\frac{\text{E.M.F.}}{\text{current}}$, *i.e.* resistance; while in the power-meter the deflection is caused by the product of current × E.M.F. In all the instruments devised by Professors Ayrton and Perry, the deflections are caused, by duly proportioning the parts, to be directly proportional to the measurements sought for in each case.

(B) REGISTERING INSTRUMENTS.—These may be divided into 2 classes —(*a*) Quantity or coulomb meters; (*b*) energy or work meters.

(*a*) *Quantity or Coulomb Meters.*—These are separated into those based upon electrolytic action, and those which are mechanical in principle.

(1) Electrolytic.—Edison's current-meters are based upon electro-deposition of metal, due to the action of a known

fractional part of the total current. The weight of the increments is ascertained periodically, and from it the total quantity of the current which has passed through the interval is deduced. The metal used consists of plates of amalgamated zinc, immersed in a solution of 90 parts zinc sulphate and 100 of pure water. In the form of meter for commercial use, 2 cells are placed as a check against each other; one, termed the "monthly cell," receiving 4 times the current of the other, which is known as the "quarterly cell." To prevent the temperature of the liquid in the cells falling so low as to freeze, a connection is made, by means of a long thin strip of brass and steel riveted together, to an incandescent lamp, which is thereby lighted, and raises the temperature as required. It is only when the temperature falls to 42° F. (5½° C.) that this tongue is sufficiently depressed to form contact, and so to light the lamp. On the temperature rising, the tongue rises, and the lamp is extinguished. Experience shows that electro-deposition, to give a true and reliable record, should not be forced or overworked in its action; and that the plates should not in their daily duty be required to do more work, or be longer in action, than they are intended for by their superficial area. In practice, about 75 per cent. only of the nominal work should be required of them. It appears to be the custom to design the duty of a meter for 3 hours' burning of each lamp per night. Thus, a 25-light meter would have its plates designed for 75 lamp-hours per night. As just stated, it is not advisable in practice to exceed 75 per cent. of this amount. However, it is seldom found that the whole of the lights are used for the entirety of the time allotted to each; and if this were so, it would merely require a larger meter to meet the case. It is said that over 300 meters on this principle are in use in New York.

Sprague's meters are based upon electro-deposit up to a certain point; *i. e.* when the intended quantity of metal, whether copper or zinc, has been deposited on the plate. The current is then reversed, and the metal is gradually dissolved again until the primary condition of the plate is reached; when, by another reversal of the current, deposition again commences. Each reversal of the current is recorded by a mechanical counter and a train and wheels. Not much practical experience has been obtained with these meters; but what has been done tends to point out that the mechanical operations involved in the reversals of the current, and in their registration, absorb a large amount of power.

(2) Mechanical.—Hopkinson's current-meter consists of a thick wire coil, in the form of a solenoid, through which the current passes to be measured. The iron core of this solenoid revolves with its central shaft by the action of the armature of a small dynamo machine placed at one end of the shaft. The core of the solenoid is in 2 parts; the lower is fixed to the shaft, while the upper is movable, being attached to a governor-ball arrangement, and sliding up and down the shaft in accordance with the variations in the rotation speed of the shaft. A shunt current passes through the dynamo and its armature, up through the lower or fixed portion of the core, (by contact only) to the sliding part, and thence to the framework of the apparatus. If the movable core be lifted, owing to the speed of rotation, by the action of the governor-balls, this circuit is broken, and the shunt current through the dynamo is interrupted. Whenever a current to be measured passes through the coil, attraction, by means of its casing, takes place between the fixed and the movable parts of the iron core. This magnetic action, which is proportional to the square of the current, tends to keep the 2 parts of the core together and in contact; while the centrifugal force of the governor-balls, which is proportional to the square of the speed of revolution, tends to break the contact by lifting the movable part. These opposite forces will, in working, balance one another, and the result is that the

system revolves with a velocity proportional to the current through the coil. As the revolutions of the shaft are transmitted continuously by a train of wheels to a set of index dials, a record is kept of the quantity of the current that has passed.

Boys's Quantity or Vibrating Meter is based upon 2 well-known principles: (1) The force acting on the armature of an electro-magnet, in any position, is proportional to the square of the current; (2) the square of the number of vibrations, say, of a pendulum, is a measure of the controlling force. Therefore, if the controlling force under which a body vibrates is due to the action of an electro-magnet on its armature, the square of the number of vibrations in a given time is a measure of the square of the electric current. In other words, the rate of vibrating is a measure of the strength of the current; and the number of vibrations is a measure of its quantity. The exact form and nature of the meter may vary in many details. One form consists, primarily, of an electro-magnet (the upper one), through the coils of which passes a portion of the main current to be measured. This magnet is placed horizontally, and a vertical rocking shaft stands between its poles. This shaft has fixed on it a soft iron armature, rounded at the ends, and free to move in the horizontal plane between the poles of the electro-magnet. The intensity of the attraction between the poles and this armature determines the rate of vibration, which, as above stated, is a measure of the strength of the current. Each vibration is itself recorded by means of an escapement, a train of wheels, and a set of index dials; and the number of vibrations thus registered becomes a measure of the quantity of the current. To add to the momentum of the vibrating body, 2 long arms, weighted at the end, are attached to the lower part of the vertical shaft. To prevent the vibrating armature from gradually coming to rest, it is arranged that, when the vibrations fall below a certain limit, by making contact, a portion of the current is sent round the coils of a second or "impulse" electro-magnet (placed underneath the "controlling" magnet), and which has an armature of a suitable form fixed on to the same shaft that carries the armature of the upper magnet. The extra motion thus given to the shaft by the attraction of the lower armature, affords the necessary impulse to the vibrating armature when required.

In Lane-Fox's quantity meter the entire current of supply is passed through the coils of a solenoid; the movable core, or plunger (the degree of insertion of which within the solenoid depends upon the intensity of the current), is made pendant from one end of a beam or balance. From the other extremity of the beam hangs a plunger, in the form of an inverted cone, which in its position of rest fills up completely, with the base of the cone, a small vertical water-pipe, the water being constantly supplied from a small cistern above. The result of the passage of an electric current through the coils of the solenoid is to suck the core or plunger deeper in, and in doing so the conical water-plug is lifted, and its diameter at the orifice of the pipe being diminished in consequence, water escapes down the pipe. The amount of this water, being directly dependent upon the intensity of the current, becomes a measure of its quantity. A cistern is provided for this overflow; and when it becomes full, it is automatically emptied. These successive operations of emptying are recorded mechanically by a train of wheels. By this means, a record is kept of the quantity of the supply.

F. H. Varley's meter is based partly upon electric and partly upon mechanical principles, the successive increments of depositions being made visible by a pointer on a curved index; and the several reversals are understood to be alterations in the mechanical direction, and not in that of the current (as in Sprague's meters).

(*b*) *Energy or Work Meters.* — (1) Boys's.—This consists of 2 parts—the indicator of energy, and the integrating

apparatus. In the indicator of energy, a balanced beam has from one end suspended a counter-weight, and from the other a hollow solenoid, free to work up and down into 2 other solenoids. The movable solenoid is wound with a considerable length of fine wire, in the upper half in one direction, in the lower in the opposite (this is to render it independent of any magnet which may be placed near it). This solenoid constitutes the high resistance shunt which measures the E.M.F. The 2 fixed solenoids are wound with thick wire, and convey the main current. The result of the action of the fixed and movable solenoids on each other is a force proportional to the product of the 2 currents, that is, to the energy expended; but the external evidence of this is the inclination of the beam, and this inclination, or rather the tangent of the inclination, is proportional to the energy being expended. The recording apparatus consists of a cylinder, which, by means of a mangle-motion, is made to reciprocate backwards and forwards by clockwork, and during its passage in each direction the cylinder is made to bear alternately against one of 2 tangent wheels, each free to be inclined in its direction of travel: both are fixed on the same swivelling frame, but only one of them bears at the same time against the cylinder. This frame is free to be inclined from the vertical in correspondence with the inclinations of the beam. The effect of this inclination of the tangent wheel is to cause the reciprocating cylinder to rotate, the speed of such rotation being proportional to the tangent of the inclination of the wheel, which is likewise proportional to the tangent of the inclination of the beam, *i.e.* to the amount of energy expended. The path of the tangent wheel on the reciprocating cylinder, when not inclined, is simply a straight line lengthways along the cylinder, and no rotation is caused; but when, owing to the inclination of the wheel, the cylinder rotates, the wheel-path becomes a spiral. The rotations of the cylinder are transmitted to a train of wheels, and registered, thus giving a record of the amount of energy expended during a given time.

(2) Deprez's instrument consists of a thick wire coil, movable upon its axis, which passes through its centre of gravity. This axis-shaft is set upon 2 knife-edges, insulated from each other, and communicating respectively with the coil; and with a metallic bar having a curved, quadrant-shaped head, which dips into a mercury cup, and thus forms connection with the main current. The shaft also carries, projecting downwards, a pendulum rod, the bob of which is intended to cause an antagonistic force; while the extension upwards of the rod forms a pointer, with a scale fixed on the frame of the apparatus. On the frame there is also a fine wire coil, on a shunt, fixed so as to surround the movable coil. The deflections on the pointer are therefore due to the product of the intensity of the current and its electro-motive force; that is, to the power developed. The readings of this instrument may be integrated either by a Deprez rotating disc and ball integrator, or by one designed by Abdank (of Cracow), having a travelling cylinder and tangent-wheel arrangement, somewhat similar to that of Boys.

(3) Ayrton and Perry's erg-meter is but a further development or sequel to their power-meter, by the addition of apparatus which integrate and record continuously the time during which the electrical energy has been imparted, as well as the variations in its amount. By this means is preserved a record of the entire work done, or of the total electrical energy supplied. As in the power-meter, 2 coils are here made use of. There is a thick wire one on the main circuit, to measure the amount of current; and a thin wire one on a shunt, joining the ends of the main circuit, to measure the difference of potential, or electromotive force, of the main circuit. The thin wire coil, of say 1000 ohms resistance, simply replaces the pendulum bob of a clock. The wires from each end of the coils pass up the sides of the pendulum rod,

and on to binding-screws, which can be joined to the supply and return cables of a house, or machine, or a system receiving electrical energy. In the immediate vicinity of the fine wire coil, fastened to the clock-case and parallel with the plane of the pendulum path, is fixed the thick wire coil, which forms part of the main circuit and has a very small resistance. The effect upon the thin wire coil of its repeated passages in front of the thick wire coil is to cause a certain pull or attraction upon its motion—either of acceleration or of retardation, according to the direction of the coiling. This action, in addition to the ordinary action of gravity upon the pendulum, will keep constantly adding to or taking from its rate of motion, in proportion to the electrical power of the circuit. This pull is the product of the magnetic moments of the 2 coils, and therefore is proportional to the product of the current and the electromotive force. The effects of these repeated accelerations or retardations upon the progress of the clock keep constantly accumulating, and their total amount can at any time be detected and ascertained by observing the amount of loss or gain which the clock has experienced. As the rate of loss or gain in the clock due to different amounts of electrical power has been previously ascertained, this knowledge of the total retardation or acceleration upon the clock is, in fact, a record of the total amount of electrical energy which has been expended, or of the work done, since the last observation of the clock.

Prof. W. Grylls Adams observes that before much can be said about these various instruments, they require further trial and comparison with one another. One important point is economy; a simple instrument will have the preference over another which may be equally effective but more complicated. If these instruments are to be used by every consumer, it is a matter of great importance that they shall not be unnecessarily expensive.

Preece advocates the adoption of a mode by which lighting may be paid for, not by measuring the quantity of electricity consumed, but by the measurement of the amount of light given as compared with that given by 1000 cub. ft. of gas. What is supplied and used is light, and what people want to pay for is light; 1000 cub. ft. of gas give a very convenient standard, and if the electric light companies could only formulate some plan by which they would charge accounts for the light supplied, he believes the public would be more ready to use it than if they were charged per volt-ampère, or any other measurement which a few understood but the majority did not. The most interesting subject is, not how electricity is to be measured, but how it is to be paid for. Boys's instruments are perfect of their kind, and Dr. Hopkinson's instrument for measuring the quantity of electricity passed into a house, though very little known, is one of the most perfect things he has ever seen. Why he objects to pay for electricity is because he believes we do not know how much light it will produce. If we agreed to pay 7*d.* per 1000 volt-ampère hours this year, the probability is that next year such improvements would be made, that the same energy which now produced 200-candle power, would then produce 2000.

Microphones.—The microphone has been so named from its power of increasing sounds resulting from mechanical vibrations transmitted by solid substances, and thus rendering audible such ordinarily inaudible sounds as a fly's footsteps on the stand of the instrument. Its action is thus described by Prof. James Blyth.

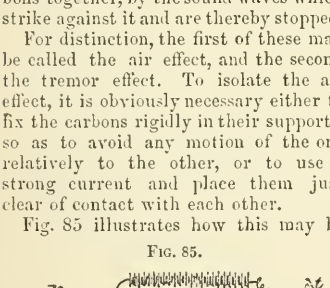
Action.—In the microphone transmitter, as usually employed in circuit with a battery and a bell telephone, are essentially 2 pieces of carbon resting lightly against each other, through which the current passes. That the instrument may work effectively, 2 things are requisite: first, that the carbons be always in contact, or at least sufficiently near for the current to pass between them; and secondly, that they may not be pressed together so tightly

as to prevent any motion of the one relatively to the other. This state of things is sufficiently well described by the term "loose contact." To understand the action of the microphone, it is necessary to find out what effects are taking place at the loose contact when the instrument is acted upon by sonorous waves. These are twofold: first, the effect produced by the sound waves (that is, the variations of density due to the condensations and rarefactions of the air), which pass directly through the air when they arrive at the loose contact; and secondly, the effect produced by tremors set up in the entire instrument, wooden supports, and carbons together, by the sound waves which strike against it and are thereby stopped.

For distinction, the first of these may be called the air effect, and the second the tremor effect. To isolate the air effect, it is obviously necessary either to fix the carbons rigidly in their supports, so as to avoid any motion of the one relatively to the other, or to use a strong current and place them just clear of contact with each other.

Fig. 85 illustrates how this may be

FIG. 85.



done: a, b, c are 3 blocks of brass firmly fixed to a heavy wooden sole-plate. To the top of a is soldered a piece of brass tube h, about 2 in. long and $\frac{5}{8}$ in. bore To the top of b is soldered a piece of similar tube k, about 4 in. long. Through c passes a fine screw s worked by a milled head m. A piece of carbon-rod c is fixed firmly into h, and has a hole $\frac{1}{4}$ in. in diameter drilled through its centre. A long piece of carbon f, pointed at one end, passes tightly through the tube k, and can be moved backwards and forwards by the screw s. A piece of indiarubber tube l is passed over the left end of the tube h, and to this is attached a mouthpiece n. By means of the wires x and y soldered to the carbon rods, they are put in circuit with the battery d (20 Grove's cells) and the telephone t, which must either have a small resistance, or be placed in a separate circuit from that containing the battery, so as to be acted upon inductively.

When the carbon f is screwed tightly into the hollow of c, the circuit is completely closed, and no sound uttered into n is heard at t. But when f is drawn gradually back until small electric arcs are seen to pass between f and c, every sound uttered into n is loudly and distinctly reproduced in the telephone t. Here is clearly only the air effect acting, and that solely upon the small electric arcs passing the carbons. It is somewhat difficult to get the sounds to last for any length of time, in consequence of the arc distance soon getting too great for the current to pass, and requiring re-adjustment. When the arc begins and ends, a sharp click is heard in the telephone; but in the interval during which the arc lasts, the sounds are distinct.

As far as the tremor effect is concerned, it is obvious that the microphone action must depend either (1) upon the variation of resistance due to variation of pressure, or (2) to variation in the extent of surface contact due to the elastic yielding of the carbons under pressure.

To test the first of these causes, Prof. Blyth made experiments on the effect of pressure upon the specific resistance of carbon. For this purpose he took a short length of carbon rod, and soldered wires to it at a short distance from each end. By means of these wires the resistance of the carbon rod was balanced in the Wheatstone bridge. Pressure was then applied by means of a lever to the carbon in a longitudinal direction. No appreciable variation in the resistance was observed even under considerable pressure; and it only be-

came manifest when the pressure was sufficient to bend or crush the carbon. Similar experiments, with the same result, have been made by Prof. Thompson. Hence it can hardly be believed that variation of specific resistance due to pressure can have the slightest effect in producing the microphone action.

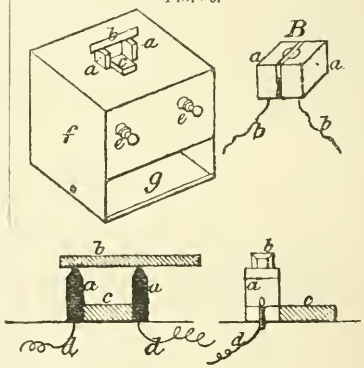
To test the second cause above mentioned—that is, the variation of resistance due to variation in the extent of surface contact due to elastic yielding under pressure—Prof. Blyth experimented as follows:—In the apparatus already described, he replaced the tubular carbon by a finely-pointed piece, so as to have 2 fine points exactly opposite each other. The resistance of the points was balanced in the bridge in the usual way. Pressure was then applied by a known number of turns or parts of a turn of the fine screw, and the change of resistance was noted. The screw was then brought back to former position, and the pressure relieved so as to allow the elasticity of the carbon to act and restore the points to their first condition. It is obvious that if the change of resistance were due merely to elastic yielding, it should now be the same as before. This was found not to be the case. From the gritty nature of the carbon, the points of contact were perpetually changing, and hence the variation of resistance produced in this way obeyed no regular law. From this irregularity it is impossible to conclude that this cause could explain the transmission of musical sounds, far less articulate speech.

As far as Blyth's experiments go, the following appears to be something like the true explanation of the microphone action. What he has termed the air and the tremor effects take place simultaneously. The tremor effect produces a jolting of the carbons sufficient to allow momentary minute electric arcs to take place between the points which are just clear of contact with each other. Simultaneously with this, the air effect comes in, and on account of the variations of density due to the condensations and rarefactions of the air, acts upon the minute electric arcs so as to vary their resistance. The tremor effect explains merely production of the musical pitch of the sounds heard in the telephone, whereas it is to the air effect that we must look for the transmission of the quality of the sounds uttered into the microphone transmitter. The microphone is thus so far a delicate make and break analogous to the old Reiss transmitter, with the important addition, however, of minute momentary gaps filled with a material which is sensitive to the minute harmonic variations of the atmospheric density which constitute sonorous vibrations. (Prof. Blyth.)

Construction.—Instructions will now be given for the construction of microphones of various forms and patterns.

(1) Simple Microphone, capable of making the tramping of a fly, &c., audible (Fig. 86).—All the battery it

FIG. 86.

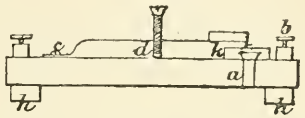


requires is a piece of carbon and zinc or copper and zinc, about 3 in. square, with a piece of blotting-paper between, damped with vinegar. It answers equally as well as an expensive battery. *f* is a box, size immaterial, say 4 in. square; over the top is stretched a piece of vegetable parchment; *a*, pieces of carbon filed to a knife-edge at top, to support small stick of carbon, *b*; *c*, piece of wood glued to *a* and to parchment top; *d*, wires connecting *a* with

binding-screws *c*. An old sewing machine needle makes a good drill for drilling the holes into which the wires are wedged tight with the point of a pin. B is another form, scarcely so sensitive, but less liable to accident from flies walking over it. *a* are 2 pieces of carbon about ¼ in. square, fastened together by being glued to a thin piece of card which reaches about half-way up. The top of the carbon, in the centre, is cupped so as to hold a small pellet of carbon, ranging in size from a mustard-seed to a pea; *b*, wires to binding-screws. When all the connections are made, place a watch at the bottom of the box at *g*, and gently push the carbon piece *b* till it is almost falling over. A little practice will soon enable any one to get a very fine balance. The finer the balance, the better the result. When the ticking of the watch can be heard distinctly, take it out and place it on the top of box, resting the ring on the piece of wood *c*. With a moderately good telephone, the ticking will be sufficiently loud to be heard across a good-sized room. For flies, cover the top with a bell glass, or put them in the box and close up the opening. When using a common pin instead of *b*, flies may be heard running about almost as distinctly as with the carbon. A human hair drawn across the parchment is heard as a rustling sound in the telephone. The experiments should be conducted in a quiet room, as the slightest conversation or movement affects the microphone, and produces a jarring noise in the telephone. (T. Cuttriss).

(2) Adjustable Microphone.—Get a piece of ⅛-in. deal, about 4 in. by 3 in., polish it up, and ebonize it. Underneath put 4 corner pieces, 2 of which are shown at *h*, Fig. 87. Next fix one of the carbon pieces on the board. In one corner of the board cut a square hole through, as at *a*, then get your carbon block and bore a hole half-way through it, making the hole wider inside (*b*). The carbon block is sunk slightly into the hole at *a*, a piece of copper wire is inserted, and melted lead is poured into the hole, binding the carbon block on and making a good connection between it and the wire, which is then connected underneath to the binding screw at *b*. Then

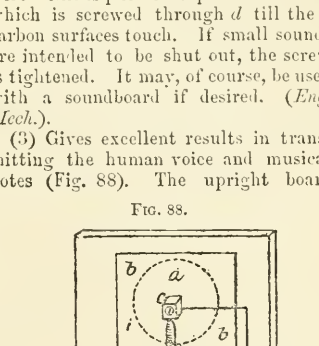
FIG. 87.



get a slip of thin "latten" brass about 2 in. long by ⅜ in. broad, and punch two small holes in it, one at one end *c*, the other in the middle *d*. At the other end a piece of gas carbon, about ⅜ in. by ¼ in. by ⅛ in., is fastened by means of melted lead The end *c* is then fastened down with a screw and washer, the carbon end in this position being about ⅛ in. from the carbon block. A small spiral is made with No. 32 copper wire—this is put on a taper wood screw, which is screwed through *d* till the 2 carbon surfaces touch. If small sounds are intended to be shut out, the screw is tightened. It may, of course, be used with a soundboard if desired. (*Eng. Mech.*).

(3) Gives excellent results in transmitting the human voice and musical notes (Fig. 88). The upright board

FIG. 88.

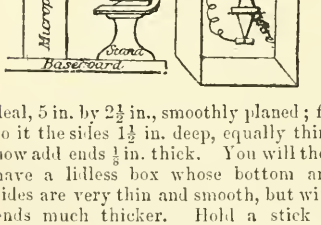


has a circular hole *a* cut through it, about 2½ in. in diameter. Over this is gummed some vegetable parchment *b*,

which, when the gum has well dried, is wetted and dried several times till quite taut. To the centre of this is fixed the upper carbon block *c* by means of a screw and a small wooden nut, and the wires are connected with battery and telephone in usual manner. I have only tried a 2½ in. hole, but am inclined to think that an improvement may be made by varying the size of the hole and the position of the carbon block on it. (T. J. Mercer.)

(4) Will transmit distinctly the loudest voice and the lowest whisper, when such are spoken 10 ft. or 12 ft. distant, without the smallest jar, and in the same tone as the speaker's voice. (Fig. 89.) Take a piece of very thin

FIG. 89.

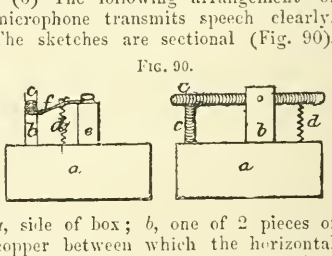


deal, 5 in. by 2½ in., smoothly planed; fix to it the sides 1½ in. deep, equally thin; now add ends ⅛ in. thick. You will then have a lidless box whose bottom and sides are very thin and smooth, but with ends much thicker. Hold a stick of cask-wax in the flame of a spirit lamp, and run it in the seams where the sides and ends join—of course having previously glued them; screw this firmly through its end, to a stout base-board 3 in. by 7 in. In this box fix an ordinary microphone; to the centre of the vibrator cement a piece of iron wire. It is only necessary now to make a stand upon which to place a horse-shoe magnet; the stand, with the magnet upon it, must be in height so that when placed upon the base-board the feet of the magnet will stand parallel to the iron wire. The magnet may be fixed to the stand, but the stand must be free, so that it can be moved backwards or forwards on the base-board, nearer to or farther from the vibrator. Having connected your batteries and telephones, bring the feet of the magnet within ⅛ in. of the iron wire (the wire must not touch the magnet). Now speak, standing 3 or 4 ft. away—your friend will then report to you through the telephone the result; if not satisfactory, move the magnet farther away, until the voice is clearly heard, and in its natural tone. The results are equally as satisfactory as wonderful, the magnet merely acting as an easily adjustable spring in controlling superfluous vibration, which is the cause of that peculiar and annoying jarring sound. (R. Blakeborough.)

(5) Get a thin bit of board about 6 in. by 3 in., supported at each corner by little feet, also 2 small blocks of carbon with a hole through the middle and a notch at the side of each; screw them into the board about 1½ in. apart by binding-screws, and across them, resting in the notches, put a bar of carbon; it will much improve it if the carbon is heated red-hot and plunged into mercury. The microphone is now complete. To connect it, join one terminal of microphone with one pole of the battery and the other with one pole of the telephone; the second terminal of the telephone is joined with the other of the battery. (E. H. Hills.)

(6) The following arrangement of microphone transmits speech clearly. The sketches are sectional (Fig. 90).

FIG. 90.

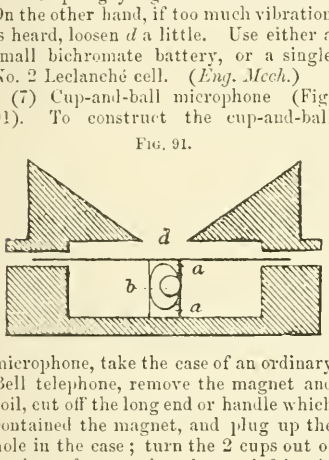


a, side of box; *b*, one of 2 pieces of copper between which the horizontal piece of pencil carbon *c* is spindled so that one end rests lightly on the other piece of pencil carbon *c*, which is fixed upright; *b*, the 2 pieces of copper mentioned before; *c*, end of the horizontal piece of carbon, under which a fine watch-spring *f* passes. One end of the spring *f* is screwed on to a wooden block *e*. The pressure of the spring *f*

against the end of the carbon *c* is regulated by the screw *d*, which passes through it. Use a Bell's telephone as the receiving instrument. Speak in a low clear tone quite close to the microphone, and if the voice cannot be heard well at the other end of the line, tighten the screw *d*, thereby easing the pressure of the spring *f* against the carbon *c*. On the other hand, if too much vibration is heard, loosen *d* a little. Use either a small bichromate battery, or a single No. 2 Leclanché cell. (*Eng. Mech.*)

(7) Cup-and-ball microphone (Fig. 91). To construct the cup-and-ball

FIG. 91.



microphone, take the case of an ordinary Bell telephone, remove the magnet and coil, cut off the long end or handle which contained the magnet, and plug up the hole in the case; turn the 2 cups out of a piece of a round carbon rod $\frac{3}{8}$ in. in diameter, and make the ball out of a piece of round carbon rod $\frac{3}{16}$ in. diameter. Secure one of the cups to the centre of the wooden case of the telephone by a small screw, and the other cup to the centre of the diaphragm of the telephone by a leaden rivet; place the carbon ball in the cup which is secured to the case, and place the diaphragm with the cup attached to it in its former position in the telephone case, having of course first carried a wire from each carbon cup to a terminal screw; see that the 2 cups are concentric; screw in the mouthpiece, and the microphone is complete. The microphone must be mounted in gimbals like a looking-glass, and slightly inclined backward or forward, until it speaks quite clearly, when it may be clamped. Each microphone has one position in which it speaks best, and this position must be found by actual trial. If the microphone is intended for ordinary use, the diaphragm should be made of thin deal, straight-grained and about $\frac{1}{8}$ in. thick; after the carbon cup is attached, the wooden diaphragm should receive, in the side against which you speak, a coat of thin white hard varnish, put on in a dry room with a wide brush.

In the sketch, *a* are the carbon cups, *b* is the carbon pea, is the diaphragm, and the shaded parts represent the telephone case, which, as drawn, is not closely screwed up. The open interior part of the case, *i.e.* the part which determines the area of the free vibrating portion of the diaphragm, should be $2\frac{1}{4}$ in. in diameter; the other dimensions may be varied according to fancy, but the carbon cup attached to the diaphragm should not be more than about $\frac{1}{4}$ in. in length. There is no difficulty in turning the carbon cups, the only tools required being a brad-awl, which makes a capital drill for carbon; an old file to smooth down the back and face of the cup, which can, however, be done with emery-paper; the stump of any old small chisel ground to a long cutting slope; and a fret-saw. It is desirable to turn a small piece of boxwood to such a shape as will fit into the cup when completed, and by pushing this lightly into the cup whilst it is running in the lathe, the interior of the cup will be smoothed, and in many cases polished. To make the ball, chuck a piece of $\frac{3}{16}$ in. round carbon rod, and at the end turn a round head, like the head of a pawn in a set of chessmen; get it as nearly round as possible—a file is the best tool for this—and then cut it off; rub off any projections on emery-paper. The remainder of the process may be done in 2 ways. (1) Tack a sheet of emery-paper on a board, secure another piece of emery-paper to a conveniently-shaped piece of wood with a flat face; put the carbon pea on the emery-paper tacked on the board, and, with the other piece of emery-paper-covered wood, rub the pea about in every direction between the two, and with a little care the pea will become nearly a true sphere. (2) The other

way, advised by Yeates, of King Street, Covent Garden, is—take a piece of sheet-steel about as thick as a screw-blade, and about 2 in. long by $\frac{3}{4}$ in. wide, soften it, chuck it by means of sealing-wax; drill a hole, about $\frac{1}{8}$ in. in diameter, through the centre—the exact centre is not required; then with a *very keen*-edged tool enlarge this hole to about $\frac{5}{32}$ in. diameter, and take care that the edges of this hole are left sharp and not rounded; then harden the plate as hard as you can make it. Take the carbon pea which you have roughed down in the lathe, put it in the hole in the steel plate, rub it round in every direction between the finger and thumb, and after a while it will pass through the hole and be almost a true sphere. I have made the carbon balls by both these processes, and though the latter is by far the more accurate, the former has answered very well. One plate will make a great many balls. In all microphones, the points actually in contact, or which regulate the current, oxidize, and when this is complete, the current will not pass. In this cup-and-ball microphone, fresh surfaces are constantly coming into contact, and a shake will always ensure this. If the microphone is properly constructed, the ball should rattle loudly when the microphone is shaken. In screwing up the microphone, the diaphragm should not be pinched too tightly. The best way is to screw it up a little too tight, and then slacken it slightly. This microphone need not be round in shape; it can easily be made square, in which case the dimensions should not be less than 4 in. by 3 in., and a mouthpiece may be dispensed with. I have made a microphone with 4 sets of cups and balls, the diaphragm being about 7 in. in diameter, and the cups arranged with 3 pairs equidistant in a circle 3 in. in diameter, and the fourth pair in the centre; the cups in the diaphragm being connected together, and the cups on the back or case also connected; with this arrangement, a very strong battery may be used, when the articulation is a little louder, but scarcely so distinct as with one pair of cups only. If a multiple microphone is made up, the cups should not be less than $1\frac{1}{2}$ in. nor more than 2 in. apart.

The receiver is made as follows:—Take a round piece of mahogany, or other dry wood, 2 in. in diameter and $\frac{1}{2}$ in. thick; in the centre make a circular hole the size of a sixpence to take the electro-magnet: on one face mark a circle the size of a bronze penny; just outside this circle, and touching it, make 3 holes equidistant from one another, and the size of No. 9 B.W.G. iron wire; in each hole put a piece of this iron wire, long enough to project a little from the wood on each side; the electro-magnet is made of a piece of the same No. 9 B.W.G. iron wire, slightly less than $\frac{5}{8}$ in. long, and the reel is the size of a sixpence, $\frac{1}{2}$ in. long, and wound with No. 36 silk-covered copper wire; the electro-magnet is placed in the hole in the wood, the end of the wire is carried out to connect with the terminals, and the whole is boiled in paraffin. Two pieces of thin wood, about $\frac{3}{16}$ in. thick and 2 in. in diameter, are also required. In one a recess is made the size of a penny and rather less than $\frac{1}{16}$ in. deep; in the other a similar recess, but with a central aperture about $\frac{1}{2}$ in. in diameter, to permit the sound to escape; 2 discs of thin iron, 5 mil. thick, or ferrotype plate, are also required. Take the disc of wood containing the electro-magnet, the wires of which have of course been led to convenient terminals, file down the ends of the 3 iron wires on one side of the disc, until one of the thin iron discs, when laid upon these 3 iron wires, will *almost* touch the core of the magnet; let this plate remain on these 3 wires, put on the recessed disc of wood, which is without the central aperture, and secure it by 3 screws. The setting of the other thin iron plate requires more care, but is done in the same way, the projecting ends of the thin wires being filed down until the other thin iron plates, when placed upon them, and the whole put in circuit with an articulating microphone, speaks distinctly: the recessed disc of wood with the central aperture is then placed upon the iron plate, and

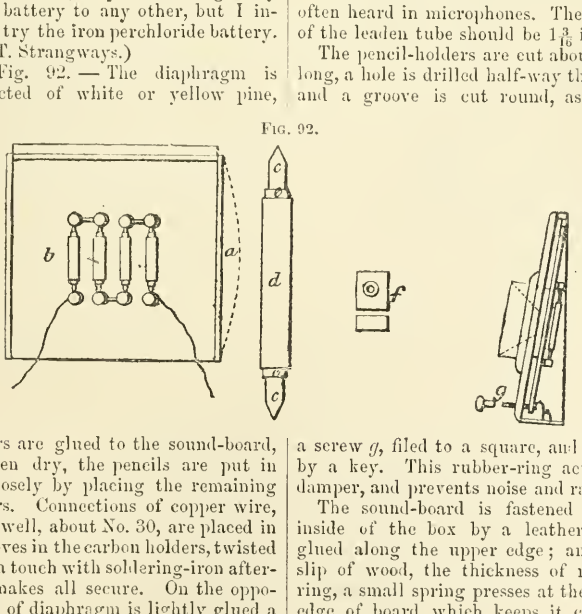
secured by 3 screws, which must not be tightened too much, or the plate will not speak clearly. We have now an electro-magnet between 2 thin iron plates, which plates are in metallic connection with one another by the 3 iron wires; one plate being adjusted at the best speaking distance from the core of the magnet, and the other plate as near to the core of the magnet as it can go without touching it at any time.

The above directions will enable any one to make both the cup-and-ball microphone and the electro-magnet receivers; but remember that a good receiver is of no use with a bad transmitter, nor a good transmitter with a bad receiver. I have had these instruments in use for 2 years: they work admirably and give no trouble. For telephone work, I prefer the gravity Daniell battery to any other, but I intend to try the iron perchloride battery. (H. B. T. Strangways.)

(8) Fig. 92. — The diaphragm is constructed of white or yellow pine, $\frac{1}{12}$ in. thick and 5 in. square; on the edges are glued 2 strips of wood *a*, about $\frac{3}{16}$ in. thick, shaped like a bridge, about $\frac{1}{2}$ in. at the middle, and tapering gradually at the ends; these are glued across the grain, and prevent the sound-board *b* from twisting. The carbon pencils *c* are made from electric-light pencils No. 2, obtained from E. Paterson, 76 Little Britain, and the pencil-holders from No. 5 pencil. The pencils are 2 in. long, neatly filed to a point, and fitted into a small leaden tube *d*. The tube used for pneumatic bells answers well. Round the carbon is glued a leather collar *e*, which secures the lead in place, and acts as a damper in preventing the sound given by the carbon itself. This is heard if a small piece of carbon is struck, and is the cause of the metallic noise so often heard in microphones. The length of the leaden tube should be $1\frac{3}{16}$ in.

The pencil-holders are cut about $\frac{7}{16}$ in. long, a hole is drilled half-way through, and a groove is cut round, as at *f*:

FIG. 92.



4 holders are glued to the sound-board, and, when dry, the pencils are put in place loosely by placing the remaining 4 holders. Connections of copper wire, cleaned well, about No. 30, are placed in the grooves in the carbon holders, twisted up, and a touch with soldering-iron afterwards makes all secure. On the opposite side of diaphragm is lightly glued a rubber-ring, about $2\frac{1}{2}$ in. in diameter, which rests when in box against the front, and the pressure is regulated by a screw *g*, filed to a square, and moved by a key. This rubber-ring acts as a damper, and prevents noise and rattling.

The sound-board is fastened to the inside of the box by a leather hinge glued along the upper edge; and on a slip of wood, the thickness of rubber-ring, a small spring presses at the lower edge of board, which keeps it close to the screw *g*.

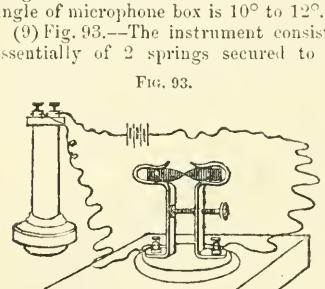
The sound-hole in mouthpiece is 1 in. in diameter, and the box is made of

well-seasoned mahogany, $\frac{1}{2}$ or $\frac{3}{4}$ in. thick, solidity being essential; the internal diameter of box is about $5\frac{1}{2}$ in., leaving a space of about $\frac{1}{4}$ in. all round the board, except at the upper edge, where the leather hinge is glued on.

When the adjusting screw allows the diaphragm to press lightly on front of box, the instrument is in order for speaking, and 8 to 10 in. distance gives first-rate results. The voice should be just as in ordinary conversation; music, such as violin, is beautifully heard through a telephone-receiver. Two or three Leclanché cells are sufficient for ordinary purposes. The microphone can be used well without induction-coil, and can be fixed to any of the existing arrangements with switch and bell. The angle of microphone box is 10° to 12°.

(9) Fig. 93.—The instrument consists essentially of 2 springs secured to a

FIG. 93.

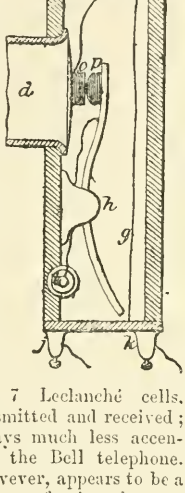


small base-piece, and each supporting at its upper end a piece of ordinary battery carbon. These 2 pieces of carbon are placed in light contact, and the 2 springs are placed in an electrical circuit in which there is also a receiving telephone of the Bell form. The instrument is represented secured to a small sounding-board. The 2 carbon-supporting springs are fastened to a single base by the binding-posts which receive the battery wires. An adjusting screw passes through one of the springs at or near its centre, and bears against a rubber button projecting from the other spring. This simple device, when placed on a table, indicates in the receiving telephone the slightest touch of the finger on the table or on the instrument. Blowing on it makes in the receiving instrument a deafening roar; drawing a hair or a bit of cotton across the carbon is distinctly audible in the receiving instrument. When the device is placed on a small sounding-board, every sound in the room is received and transmitted. An ant running across the sounding-board can be plainly heard, and a touch upon the instrument or the table which supports it, which without the microphone would be entirely inaudible, can be distinctly heard in the receiving telephone by aid of the instrument, even though miles intervene. When it is placed on a violin, blowing lightly upon the strings produces æolian harp tones in the receiver, and a song sung to the violin is rendered in the receiving instrument with an æolian harp accompaniment. When mounted on a violin or sounding-board, it will transmit articulate speech, uttered in any portion of a room of ordinary size; it will receive and transmit the music of a piano, and even the sounds of turning the sheets of music may be heard. Whistling, flute music, and other sounds are transmitted with their characteristics of volume, pitch, and timbre. This instrument, although so very simple, is capable of doing all that has been done by other instruments of an analogous character, and it will be determined by further experiment whether it will do more. Although carbon contact points are preferable, they are not absolutely essential to the operation of the instrument, as metallic points will do the same things, but not so satisfactorily. (G. M. Hopkins.)

(10) Microphone for reproducing Speech (Fig. 94).—It consists of a box of thin wood, the front of which is perforated with a hole large enough to receive the tube of a common string telephone, the parchment membrane *d*, stretched over the inner end of which, is kept level with the surface of the board on the side at which the microphone is placed. The membrane *d* carries in its centre a small piece of metallized pine charcoal *c*, which is connected by the

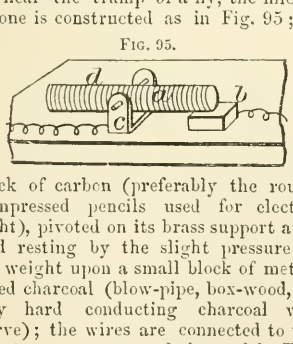
wire g and binding-screw k to the battery wire. A vertical lever, delicately pivoted on 2 points at h, carries at its upper end another piece of similar charcoal p, which is lightly pressed against the piece c. The lever is connected with the circuit by means of the wire and binding-screw j, and the pressure with which it bears on the charcoal, carried by the membrane d, is regulated by a light spring and silk thread actuated by the tension screw t. With a battery of 6 or 7 Leclanché cells, words can be transmitted and received; but they are always much less accentuated than with the Bell telephone. The apparatus, however, appears to be a neat and handy form of microphone to employ for speaking purposes, and can be made very cheaply. (Th. du Moncel.)

FIG. 94.



(11) Hughes's Microphone.—In order to hear the tramp of a fly, the microphone is constructed as in Fig. 95; a,

FIG. 95.



stick of carbon (preferably the round compressed pencils used for electric light), pivoted on its brass support at c, and resting by the slight pressure of its weight upon a small block of metallized charcoal (blow-pipe, box-wood, or any hard conducting charcoal will serve); the wires are connected to the pivot support at c, and charcoal b. This structure is fastened to any small board d of pine, $\frac{1}{2}$ in. thick, and 3 in. or 4 in. square. This will also perfectly transmit articulate speech, if spoken to not closer than 1 ft.; if louder tones are desired, put a small weight on a, and speak within a few inches of the microphone.

(12) Making Plates for Microphones.—The following process for making very thin plates for microphonic purposes, is given by Trichasson, of Mourmelon-le-Grand. A sheet of ordinary tinned iron of any thickness is cut into plates, and rubbed vigorously on both faces with a dry linen cloth. This operation is to clean away all grease. A plate is then taken and plunged vertically in a bath of nitric acid until it is entirely immersed. Acid which has already served in Bunsen batteries will answer very well, or better still, the nitric acid of commerce, diluted with $\frac{1}{4}$ water. It is necessary to remove the plates from the bath from time to time, in order to see whether the required thickness has been reached. When this is attained, the plate is washed several times in water to remove the black layer of oxide. The plate is then allowed to dry, and afterwards varnished on both sides with Japan varnish, to prevent oxidation. This process permits of making microphone and telephone diaphragms as thin as may be desired, and at little cost.

Motors.—This section may be divided into 2 parts: (1) the principles and practice of the construction of electro-motors, and (2) their application. The first may be best studied from Prof. Thompson's Cantor Lecture, before alluded to.

Construction.—An electro-motor, or electro-magnetic engine, is one which does mechanical work at the expense of electric energy, whether the magnets which form the fixed part of the machine be permanent magnets of steel or electro-magnets. Any of the 4 kinds of dynamo can be used as a motor, though some more appropriately than others. All are electro-magnetic in principle; *i.e.* there is some part, fixed or moving, which is an electro-magnet, and which attracts and is attracted magnetically. A magnet will attract the opposite pole of another magnet, and pull it round; also, every magnet

placed in a magnetic field tends to turn round and set itself along the lines of force. Supposing a small magnetic needle to be confined at right angles to the lines of force in a simple magnetic field, produced between the poles of 2 strong magnets, one on the right, the other on the left, then shortening the lines of force has the effect of rotating the magnetic needle upon its centre, through an angle of 90°. Very soon after the invention of the electro-magnet, many perceived that it would be possible to construct an electro-magnetic engine, in which an electro-magnet, placed in a magnetic field, should be pulled round; and further, that the rotation should be kept up continuously by reversing the current at an appropriate moment.

A mere coil of wire, carrying a current, is acted upon when placed in the magnetic field, and is pulled round as a magnet is. On this principle was constructed the earliest electric motor of Ritchie, well known in many forms, but little better in reality than a toy.

Jacobi constructed a multipolar machine for his electric boat. It had 2 strong wooden frames, in each of which 12 electro-magnets were fixed, their poles being set alternately. Between them, upon a wooden disk, were placed another set of electro-magnets, which, by the alternate attraction and repulsion of the fixed poles, were kept in rotation, the current which traversed the rotating magnets being regularly reversed at the moment of passing the poles of the fixed magnets, by means of a commutator consisting of 4 brass-toothed wheels, having pieces of ivory or wood let in between the teeth for insulation. Jacobi's motor is, in fact, a very advanced type of dynamo.

An earlier rotating apparatus, and, like Ritchie's motor, a mere toy, was Sturgeon's wheel, described in 1823. This instrument, interesting as being the forerunner of Faraday's disk dynamo, is the representative of an important class of machines, namely, those which have a sliding contact merely, and need no commutator.

A fourth class may be named, wherein the moving part, instead of rotating upon an axis, is caused to oscillate backwards and forwards. Prof. Henry constructed, in 1831, a motor with an oscillating beam, alternately drawn backwards and forwards by the intermittent action of an electro-magnet. Dal Negro's motor of 1833 was of this class; in it a steel rod was caused to oscillate between the poles of an electro-magnet, and caused a crank, to which it was geared, to rotate in consequence. A distinct improvement in this type of machine was introduced by Page, who employed hollow coils or bobbins as electro-magnets, which, by their alternate action, sucked down iron cores into the coils, and caused them to oscillate to and fro. Motors of this kind form an admirable illustration of one of the laws of electro-magnetics, to the effect that a circuit acts on a magnetic pole in such a way as to make the number of magnetic lines of force that pass through the circuit a maximum.

Page's suggestion was further developed by Bourbouze, who constructed a motor which looks like an old type of steam-engine. It has a beam, crank, fly-wheel, connecting-rod, eccentric valve-gear, and slide-valve; but for cylinders, 4 hollow electro-magnets; for pistons, iron cores, that are alternately sucked in and repelled out; and for slide valve, a commutator, which, by dragging a pair of platinum-tipped springs over a flat surface made of 3 pieces of brass separated by 2 insulating strips of ivory, reverses at every stroke the direction of the currents in the coils of the electro-magnets. It is a very ingenious machine, but in point of efficiency far behind many other electric motors.

A fifth class of electric motors owes its existence to Froment, who, fixing a series of parallel iron bars upon the periphery of a drum, caused them to be attracted, one after the other, by electro-magnets, and thus procured a continuous rotation.

Last of the various types of motor may be enumerated a class in which the rotating portion is enclosed in an eccen-

tric frame of iron, so that as it rotates it gradually approaches. Little motors, working on this principle of "oblique approach," were invented by Wheatstone, and have long been used for spinning Geissler tubes, and other light experimental work. More recently, Trouvé and Wiesendanger have sought to embody this principle in motors of more ambitious proportions, but without securing any great advantage.

All the early attempts came to nothing, for 2 reasons: there was no known economical method of generating electric currents, and the great physical law of the conservation of energy was not recognised. While voltaic batteries were the only available sources of electric currents, economical working of electric motors was hopeless; for a voltaic battery, wherein electric currents are generated by dissolving zinc in sulphuric acid, is a very expensive source of power. To say nothing of the cost of the acid, the zinc—the very fuel of the battery—costs more than 20 times as much as coal, and is a far worse fuel; for whilst 1 oz. of zinc will evolve heat to an amount equivalent to 113,000 foot-lb. of work, 1 oz. of coal will furnish the equivalent of 695,000 foot-lb.

Now, if a galvanometer is placed in circuit with the electric-motor and the battery, it is found that when the motor is running it is impossible to force so strong a current through the wires as that which flows when the motor is standing still. There are only 2 causes that can stop such a current flowing in a circuit; either an obstructive resistance, or a counter-electromotive force. At first, the common idea was that, when the motor was spinning round, it offered a greater resistance to the passage of the electric current than when it stood still. Jacobi, however, discerned that the observed diminution of current was really due to the fact that the motor, by the act of spinning round, began to work as a dynamo on its own account, and tended to set up a current in the circuit in the opposite direction to that which was driving it. The faster it rotated, the greater was the counter-electromotive force (or "electromotive force of reaction") developed. In fact, the theory of the conservation of energy requires that such a reaction should exist. In the converse case, when employing mechanical power to generate currents by rotating a dynamo, directly we begin to generate currents—*i.e.* to do electric *work*—it requires much more power to turn the dynamo than when no electric work is being done. In other words, there is an opposing reaction to the mechanical force applied in order to do electric work. An opposing reaction to a mechanical force may be termed a "counter-force." When, on the other hand, we apply (by means of a voltaic battery, for example) an electromotive force to do mechanical work, there is an opposing reaction to an electromotive force, or a "counter-electromotive force."

The existence of this counter-electromotive force is of the utmost importance, in considering the action of the dynamo as a motor, because upon its existence and magnitude depends the degree to which a motor enables us to utilize energy supplied to it in the form of an electric current. In discussing the dynamo as a generator, were pointed out some considerations whose observance would improve their efficiency; many of these—*e.g.* the avoidance of useless resistances, unnecessary iron masses in cores—apply to motors. The freer a motor is from such objections, the more efficient will it be; but its efficiency in utilizing the energy of a current depends not only on its efficiency in itself, but on the relation between the electromotive force which it generates when rotating, and the electromotive force (or "electric pressure") at which the current is supplied to it. A motor which itself in running generates only a *low* electromotive force, cannot, however well designed, be an *efficient* or economical motor when supplied with currents at a *high* electromotive force. Dynamos used as motors must be supplied with currents at electromotive forces adapted to them. Even a perfect motor—one without friction or resistance of any

kind—cannot give an "efficient" or economical result, if the law of efficiency is not observed in the conditions under which the electric current is supplied to it.

The efficiency with which a perfect motor utilizes the electric energy of the current depends upon the ratio between this counter-electromotive force and the electro-motive force of the current that is supplied by the battery. No motor ever turns into useful work the whole of the currents that feed it, for it is impossible to construct machines without resistance, and whenever resistance is offered to a current, part of the energy of the current is wasted in heating the resisting wire. Let the symbol W stand for the whole electric energy of a current, and let w stand for that part of the energy which the motor takes up as useful work from the circuit. All the rest of the energy of the current, or $W-w$, will be wasted in useless heating of the resistances. But to work a motor under the conditions of greatest economy, there must be as little heat-waste as possible; or, in symbols, w must be as nearly as possible equal to W. The ratio between the useful energy thus appropriated and the total energy spent, is equal to the ratio between the counter-electromotive force of the motor, and the whole electromotive force of the battery that feeds the motor. Let this whole electromotive force with which the battery feeds the motor be E, and let the counter-electromotive force be e: then the rule is

$$w : W = e : E;$$

or, expressed as a fraction,

$$\frac{w}{W} = \frac{e}{E}$$

If the resistances of the circuit are constant, the current c, observed when the motor is running, will be less than C, the current while the motor is standing still. But from Ohm's law we know that

$$c = \frac{E - e}{R}.$$

Hence $\frac{C - c}{C} = \frac{e}{E} = \frac{w}{W}$. From which, it appears that we can calculate the efficiency at which the motor is working by observing the ratio between the fall in the strength of the current and the original strength. This mathematical law of efficiency has been strangely misapprehended. Another law, discovered by Jacobi, not a law of efficiency at all, but a law of maximum work in a given time, has usually been given instead. Jacobi's law is as follows:—The mechanical work given out by a motor is a maximum when the motor is geared to run at such a speed that the current is reduced to half the strength that it would have if the motor was stopped. This implies that the counter-electromotive force of the motor is equal to half of the electromotive force furnished by the battery or generator. Under these circumstances, only half the energy furnished by the external source is utilized, the other half being wasted in heating the circuit. If Jacobi's law were indeed the law of efficiency, no motor, however perfect in itself, could convert more than 50 per cent. of the electric energy supplied to it into actual work. Siemens has shown that a dynamo can be, in practice, so used as to give out more than 50 per cent. of the energy of the current. It can, in fact, work more efficiently if it be not expected to do its work so quickly. Siemens has, in fact, proved that if the motor be arranged so as to do its work at less than the maximum rate, by being geared so as to do much less work per revolution, but yet so as to run at a higher speed, it will be more efficient; that is to say, though it does less work, there will also be still less electric energy expended, and the ratio of the useful work done to the energy expended will be nearer unity than before.

The algebraic reasoning is as follows:—If E be the electromotive force of the generator when the motor is at rest, and c be the current which flows at any time, the electric energy W, expended in unit time, will be (as expressed in watts) given by the equation,

$$W = Ec = E\frac{(E - c)}{R}. \quad . \quad . \quad (1)$$

When the motor is running, part of this electric energy is being spent in

doing work, and the remainder is wasting itself in heating the wires of the circuit. We have already used the symbol w for the useful work (per second) done by the motor. All the energy which is not thus utilized is wasted in heating the resistances. Let H represent this heat. Its mechanical value will be HJ, where J stands for Joule's equivalent. Then we shall have

$$W = w + HJ.$$

But by Joule's law the heat-waste of the current, whose strength is c, running through resistance R, is expressed by the equation

$$HJ = c^2R.$$

Substituting this value above, we get

$$W = w + c^2R, \quad . \quad . \quad . \quad (2)$$

which we may also write

$$w = W - c^2R.$$

But by equation (1) $W = Ec$, whence

$$w \; Ec - c^2R, \quad . \quad . \quad . \quad (3)$$

and writing for c its value, $\frac{E - e}{R}$, we get

$$w = \frac{(E - e) \quad (E - \{E - e\})}{R}$$

or, $$w = e\frac{E - e}{R} \quad . \quad . \quad . \quad . \quad (4)$$

Comparing equation (5) with equation (1), we get the following :—

$$\frac{w}{W} = \frac{e\,(E - e)}{E\,(E - e)},$$

or, finally, $$\frac{w}{W} = \frac{e}{E}$$

This is, in fact, the mathematical law of efficiency, so long misunderstood until Siemens showed its significance. It may appropriately be called the law of Siemens. Here the ratio $\frac{w}{W}$ is the measure of the efficiency of the motor, and the equation shows that we may make this efficiency as nearly equal to unity as we please, by letting the motor run so fast that e is very nearly equal to E : which is the true law of efficiency of a perfect motor supplied with electric energy, under the condition of constant external electromotive force.

Now go back to equation (3), which is —

$$w = Ec - c^2R.$$

In order to find what value of c will give us the maximum value for w (which is the work done by the motor in unit time) we must take the differential coefficient and equate it to zero.

$$\frac{dw}{dc} = E - 2cR = o\,;$$

whence we have

$$c = \tfrac{1}{2}\frac{E}{R}.$$

But by Ohm's law, $\frac{E}{R}$ is the value of the current when the motor stands still. So we see that, to get maximum work per second out of our motor, the motor must run at such a speed as to bring down the current to half the value which it would have if the motor were at rest. In fact, we here prove the law of Jacobi for the maximum rate of doing work. But here, since—

$$c = \frac{E - e}{R} = \tfrac{1}{2}\frac{E}{R}$$

it follows that—

$$E - e = \tfrac{1}{2}E\,;$$

or $$\frac{e}{E} = \tfrac{1}{2},$$

whence it follows also that—

$$\frac{w}{W} = \tfrac{1}{2}.$$

That is to say, the efficiency is but 50 per cent. when the motor does its work at the maximum rate.

Throughout it has been supposed that the motor is to be worked with a supply of current furnished at a fixed electromotive force. It is convenient and wise to make such a condition the basis of the argument, because this is probably the condition under which electric power will be distributed over large areas. It is true that this is not the only condition of supply, for a generator or system of generators may be worked so as to yield a constant current. And it would be quite possible to formulate a set of rules for the efficiency and maximum duty of motors under this condition. But this method of distributing electric power is far less likely to be of importance in the near future, than distribution with constant electro-

motive force; though for transmission of power to an isolated station, the case becomes of importance. One simple problem is worthy of mention. Suppose that one is desirous of working a motor so as to do work at the rate of a specified number of horse-power, and that the wire available to bring the current cannot safely stand more than a certain current without being in danger of becoming heated unduly; it might be desirable to know what electromotive force such a motor ought to be capable of giving back, and what electromotive force must be applied at the transmitting end of the wire. Let N stand for the number of horse-power to be transmitted, and c for the maximum strength of current that the wire will stand (expressed in ampères). Then, by the known rule for the work of a current, since—

$$\frac{ec}{746} = \mathrm{N}, \quad c = \frac{746\ \mathrm{N}}{e}$$

gives the condition as to what electromotive force (in volts) the machine must be capable of giving, when run at the speed it is eventually to run at as a motor. Moreover, the primary electromotive force E must be such that

$$\frac{\mathrm{E}-e}{\Sigma\mathrm{R}} = c$$

where $\Sigma\mathrm{R}$ is the sum of all the resistances in the circuit. Whence,

$$\mathrm{E} = e + c\Sigma\mathrm{R}.$$

Which is the required condition.

Another problem in the application of motors to transmission of power, which vitally affects their construction, is the determination of the relation of the heat-waste to the electromotive force at which the current is supplied to the motor.

If, as before, $\Sigma\mathrm{R}$ stands for the sum of all the resistances in the circuit, then by Joule's law the heat-waste is (in mechanical measure)

$$\mathrm{HJ} = \mathrm{C}^2\Sigma\mathrm{R}.$$

And since $c = \dfrac{\mathrm{E}-e}{\Sigma\mathrm{R}}$, we may write the heat-waste as

$$\mathrm{HJ} = \frac{(\mathrm{E}-e)^2}{\Sigma\mathrm{R}}.$$

Suppose that, without changing the resistances of the circuit, we can increase E, and also increase e, while keeping $\mathrm{E}-e$ the same as before, it is clear that the heat-loss will be precisely the same as before. But how about the work done? Let the two new values be respectively E′ and e'. Then the electric energy expended is—

$$\mathrm{W}' = \frac{\mathrm{E}'\,(\mathrm{E}'-e')}{\Sigma\mathrm{R}}$$

and the useful work done is—

$$w' = \frac{e'\,(\mathrm{E}'-e')}{\Sigma\mathrm{R}}$$

That is to say, with no greater loss in heating, more energy is transmitted and more work done. Also the efficiency is greater, for

$$\frac{w'}{\mathrm{W}'} = \frac{e'}{\mathrm{E}'};$$

and this ratio is more nearly equal to unity than $\dfrac{e}{\mathrm{E}}$, because both E and e have received an increment arithmetically equal. Clearly, then, it is an economy to work at high electromotive force. The importance of this matter, first pointed out by Siemens and later by Marcel Deprez, cannot be overrated. But how to obtain this higher electromotive force. One very simple expedient is that of driving both generator and motor at higher speeds. Another way is to wind the armatures of both machines with many coils of wire having many turns. This expedient has, however, the effect of putting great resistances into the circuit. This circumstance may, nevertheless, be no great drawback, if there is already a great resistance in the circuit—as, for example, the resistance of many miles of wire through which the power is to be transmitted. In this case, doubling the electromotive force will not double the resistance. Even in the case where the line resistance is insignificant, an economy is effected by raising the electromotive force. For, as may be deduced from the equations, when $\mathrm{E}-e$ is kept constant, the effect of doubling the electromotive force is to double the efficiency when the resistance of the line

is very small as compared with that of the machines, and to quadruple it when the resistance of the line is very great as compared with that of the machines. It is, in fact, worth while to put up with the extra resistance, which we cannot avoid, if we try to secure high electromotive force by the use of coils of fine wire of many turns. It is true that the useful effect falls off, *cæteris paribus*, as the resistance increases; but this is much more than counterbalanced by the fact that the useful effect increases in proportion to the square of the electromotive force.

In the recent attempt of Marcel Deprez to realize these conditions in the transmission of power from Miesbach to Munich, through a double line of telegraph wire over a distance of 34 miles, very high electromotive forces were actually employed. The machines were 2 ordinary Gramme dynamos, the magnets being series-wound, similar to one another, but their usual low-resistance coils had been replaced by coils of very many turns of fine wire. The resistance of each machine was consequently 470 ohms, whilst that of the line was 950 ohms. The velocity of the generator was 2100 revolutions per minute; that of the motor, 1400. The difference of potential at the terminals of the generator was 2400 volts; at that of the motor, 1600 volts. According to Prof. von Beetz, the mechanical efficiency was found to be 32 per cent. Deprez has given the rule that the efficiency $\frac{w}{W}$ is obtained, in the case where 2 identical machines are employed, by comparing the 2 velocities at the 2 stations. Or

$$\frac{W}{w} = \frac{N}{n},$$

where N is the speed of the generator, n that of the motor. There is, however, the objection to this formula, that the electromotive forces are not proportional to the speeds, unless the magnetic fields of the 2 machines are also equally intense, and the current running through each machine is the same. This is not the case if there is leakage along the line. Moreover, when there are resistances in the line, the ratio of the 2 electromotive forces of the machines is not the same as the ratio of the 2 differences of potentials, as measured between the terminals of the machines.

Turning back to consider some points in the design and construction of motors, it will be found that many of the rules already suggested (pp. 118–24) are applicable also to motors.

In the dynamo used as a generator, the capacity for doing work increases as the fifth power of the linear dimensions; by doubling a dynamo in length, breadth, and thickness, we have a machine weighing 8 times as much, costing less than 8 times as much, but capable of doing 32 times the work, and that with a great gain in economy in working. The same thing is true of motors.

In the prospect of an immediate field of usefulness opening out for motors, so soon as we have such a thing as regular town supplies of electric currents laid on, it is most important that motors should be designed, not simply to work with the constant electromotive force supplied at the electric mains, but designed also to work at uniform speeds. It is highly important, in driving many kinds of machinery, that the speed should be regular, and that the motor should not "run away" as soon as the stress of the cutting tool is removed. Deprez and Perry have solved a converse problem to this, namely, that of getting a dynamo to feed a circuit with currents, at a constant electromotive force, when driven with uniform speed, the solution consisting in using certain combinations for the field magnets, which give an initial magnetic field, independently of the actual current furnished by the dynamo itself. This problem may be applied conversely, and motors may be built with a combination of arrangements for their field-magnets, such that, when supplied with currents at a certain constant electromotive force, their speed shall be constant, whatever the work or no work which

they may be doing. The difficulty in the problem—a mere matter for experiment and calculation—is to find the critical number of volts of electromotive force at which this will hold good. It is, in fact, the converse to the operation of finding the critical velocity at which one of Deprez's or Perry's combination dynamos must be driven, in order that it may give a constant electromotive force. Deprez has constructed motors upon this plan, which run at a perfectly uniform speed, quite irrespective of the work being done: whether lifting a load from the ground, or letting this load run down to the ground, or without any load at all. Ayrton and Perry have a motor weighing only 350 lb., which will give an effective power equal to 8 h.-p.; and without any mechanical governor, without anything, in fact, in the nature of a moving governor, it always goes at the same speed, whatever work it has to do.

It is possible to use as a motor any direct-current dynamo, whether the field-magnets be series-wound, shunt-wound, separately excited, or permanently magnetized. There is this curious point of difference. Suppose the dynamo to be arranged so as to work as a generator, and then to be supplied with currents from an exterior source, to make it work as a motor. If the dynamo is series-wound, it will run the reverse way (or against its brushes), no matter which way the currents run through it. If shunt-wound, it will run with its brushes, whichever direction the current runs through it. The direction of rotation taken by the separately-excited and the magneto-machine will also be with the brushes, if the current is in the right direction, through the armature. These points have to be taken into account in any attempt to combine the different systems.

In applying to motors rules and suggestions such as were applied to generators, it will be found that, whilst some of them apply directly, others are singularly in contrast. For example, it is advisable, for the sake of steadying the currents in generators, to use large and long field-magnets with plenty of iron, and with heavy pole-pieces. In the case of motors there is no such necessity, for we want here to produce a uniform steady rotation. Even if the impulses be intermittent, the mechanical inertia of the moving parts will steady the motion. Electric currents have no such inertia (except in so far as the self-induction in a circuit exerts an influence like that of inertia), and hence the precautions for generators. In the case of generators, to produce steady currents, we had to multiply coils on the armature in many separate paths, grouped round a ring or a drum, involving a complicated winding, and a collecting apparatus consisting of many segments. In motors, no such necessity exists, provided only we arrange the coils that there shall be no dead-points. For large motors, it may be advisable to multiply the paths and segments for other reasons (as, for example, to obviate sparking at the collectors), but for securing steady running, the inertia of the moving parts spares us (at any rate, in small machines) the complication of parts which was expedient in the generator. Some of the most successful of the little motors that have recently appeared—those, for example, of Deprez, Trouvé, and Griscom—have for their armatures the simple old shuttle-wound Siemens armature of 1856, and in these is the disadvantage of dead-points to take into account. Deprez, in his first motors, placed this armature longitudinally between the poles of a horse-shoe magnet, with the axis parallel to the limbs. He has also constructed motors with 2 such armatures on one spindle, one of the coils being 90° in advance of the other, so that while one was at the dead-point, the other should be in full action. The same suggestion has been carried out in Akester's motor. Trouvé has tried to get over the dead-points by utilizing the method of oblique approach. The Griscom motor, which has little copper rollers as commutator brushes, has for field-magnets a compact tubular electro-magnet wound in series with the armature. It has the disadvantage of

dead-points. There is, in all these motors, the disadvantage that at every half-revolution the magnetism of the armature core is reversed; and as in all these forms this core is of solid iron, there must be waste by heating in the cores. In fact, to the rotating armatures of motors, as to those of generators, apply all the rules about slitting to get rid of induced eddy-currents, avoiding idle coils and useless resistances. The rules about proper pole-pieces, adjustable brushes, and multiplication of contacts, are mostly applicable to motors also as well as to generators.

In order to meet the case of a handy and reliable motor, Prof. Thompson designed a machine in which the field-magnets, which also constitute the bed-plate of the motor, are of malleable cast-iron, of a form that can be cast in one, or at most two, pieces. Their form is that of a Joule's magnet, with large pole-pieces, and wound with coils, are ranged partly in series, partly as a shunt, in certain proportions, so as to give a constant velocity when worked with an external electromotive force of a certain number of volts. As an armature, he employs a form which unites simplicity with efficiency for the end desired; he modifies the old Siemens armature by embedding, as it were, one of these shuttle-shaped coils within another, at right angles to one another. And having duplicated the coils, he duplicates the segments of the commutator, which therefore becomes either a 4-part collector or else a double collar, according to circumstances. There are no solid iron parts in the armature, but the cores are made of thin pieces of sheet iron, stamped out and strung together.

Reckenzaun's motor is interesting, because its armature, though a drum-armature in form, in reality consists of independent coils, connected, like those of the Brush dynamo, to separate commutators. There are, in fact, 4 commutators, grouped as 2 twos, and 2 pairs of brushes in contact with them.

De Meritens employs a ring armature very like that of Gramme, but places it between very compact and light field-magnets, which form a framework to the machine. There is one point about this machine of great interest, which is, however, a later addition. It is provided with a reversing gear. In it are 2 pairs of brushes; the 2 upper are fixed to a common brush-holder, which turns on a pivot, and can be tilted by pressing a lever handle to right or to left. The 2 lower brushes are also fixed to a holder. Against each brush-holder presses a little ebonite roller, at the end of a bent steel spring, fixed at its middle to the handle. The result of this arrangement is that, by moving the lever, the brushes can be made to give a lead in either direction, and so start the motor rotating in either direction. Such a reversing gear is obviously a most essential adjunct for industrial applications of motors, and if the difficulties of sparking at the brushes, caused by the sudden removals of them from the collector, be obviated, must prove much better than any mechanical device to reverse the motion, by transferring it from the axle of the motor through a train of gearing to some other axle. One great advantage of electric motors is, that they can be so easily fixed directly on the spindle of the machine which they are to drive; an advantage not lightly to be thrown away.

Application. — When once we have electrical mains of sufficient capacity carried from central stations to our houses, how simple a matter it will be to combine lighting with domestic operations, and even the larger operations required for purposes of trade; for each motor of a series, placed in parallel circuit, performs the work required of it independently of all the others, and independently of the generating machine, provided only that the generator is capable of producing the power it is called upon to furnish.

Three conclusions are to be drawn, which are the fundamental principles of the theory of the electrical transmission of power.

I. The motor, as a machine, is entirely independent of the generator, and

must be designed for the particular work it has to do without reference to the generator.

II. The current depends upon the load on the motor, and upon no other thing whatever.

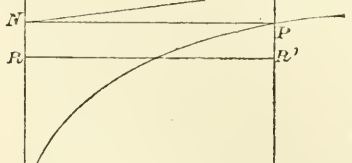
III. The speed depends upon the E.M.F. of the generator, and the total resistance in the circuit of the machines. If the mains which supply the current to the motor be maintained at a constant potential, and the motor be separately excited, or have permanent magnets, the speed is proportional to the potential of the main, less the loss of potential due to the resistance of the armature.

As a practical corollary, the generator must be designed to give the current required of it by the motor, and E.M.F. sufficient after allowing for fall of potential through the resistance of the mains, to give the requisite speed. Keeping these points in view, it is easy to design a combination of machines for performing any particular work, to calculate exactly the efficiency of the combination, and to account for the various losses that occur.

To put these considerations in a mathematical form:—The first problem is, given a main with a constant E.M.F., denoted by E, to construct a dynamo machine, drawing its current from the main, to work with a given load L, and at a given number of revolutions n per minute.

Take Ox Oy (Figs. 96, 97) as axes of co-

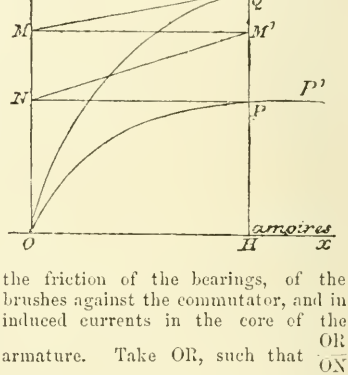
FIG. 96.



ordinates; along Oy cut off OM, representing the E.M.F. of the main in volts. The makers of each type of dynamo machine know approximately the percentage of energy their machines absorb in producing the necessary magnetic field. Take a point N in OM, such that the ratio $\frac{ON}{OM}$ is equal to this percentage.

Again, it is known that a dynamo is not an absolutely perfect machine, but that a certain amount of energy is wasted in

FIG. 97.



the friction of the bearings, of the brushes against the commutator, and in induced currents in the core of the armature. Take OR, such that $\frac{OR}{ON}$ represents the efficiency of the machine. This, in the case of the Siemens machine, is at least 90 per cent. From Ox cut off OH, such that the rectangle OHR'R represents the power required from the motor expressed in watts. Then OH is the current passing through the motor, measured in ampères, and HP is the inverse E.M.F. The proper motor, therefore, is that dynamo which, when running at the given number of revolutions n per minute, has a characteristic curve passing through the point P. The total efficiency is evidently the ratio of the rectangle OHR'R to the rectangles OHM'M, which is equal to $\frac{HR'}{HM'}$; the electrical efficiency is $\frac{HP}{HM'} = \frac{E'}{E}$, the ratio of the inverse E.M.F. of the motor to the E.M.F. of the main. The energy spent in magnetization is measured by

PNMM′, and the tangent of the angle PNM′ represents the resistance of the armature and magnets.

The second problem is:—Given a motor requiring a certain current and E.M.F. for the work it has to do, to construct a suitable generator, the distance between the machines being represented by an electrical resistance R measured in ohms. Let OPP′ be the characteristic curve of the motor, when running at the required speed; ON the E.M.F. in volts, and OH the current in ampères. Let R′ be the sum of the resistances of the motor and conductor. Draw PN perpendicular to Oy, and make the angle PNM′ having its tangent equal to R′; then M′H represents the difference of potential between the terminals of the generator. Produce HM′ to Q, so that $\frac{QM'}{QH}$ is the ratio of the energy expended in producing the magnetic field to the total energy of the machine; then the generator is that dynamo which, when running at its proper speed, has a characteristic curve passing through the point Q.

The electrical efficiency of the combination is the ratio $\frac{PH}{QH}$, *i.e.* the ratio of the E.M.F. of the motor to the E.M.F. of the generator, which, if the machines are similar, is equal to the ratio of their speeds. The energy converted into heat in the wires of the machine, and in the conductor, is NPQS; and the total efficiency of the combination is the ratio of the electromotive forces, multiplied by the product of the efficiencies of the 2 machines, considered separately. The conductor connecting the 2 machines has been assumed to be perfectly insulated, though this is not practically attained. (A. Siemens.)

Railways. — The Portrush electric railway extends from Portrush a distance of 6 miles. The line is single, and has a gauge of 3 ft. The gradients are exceedingly heavy, being in parts as steep as 1 in 35. The curves are also in many cases very sharp, having necessarily to follow the existing road. There are 5 passing places, in addition to the sidings at the termini and at the carriage depôt. About 1500 yd. from the end of the line is a waterfall on the river Bush, with an available head of 24 ft., and an abundant supply of water at all seasons of the year. Turbines are being erected for employing the fall for working the generating dynamo machines, and the current will be conveyed by means of an underground cable to the end of the line. At present the line is worked by a small steam engine.

The system employed may be described as that of the separate conductor. A rail of T-iron, weighing 19 lb. to the yd., is carried on wooden posts, boiled in pitch and placed 10 ft. apart, at a distance of 22 in. from the inside rail and 17 in. above ground. The conductor is connected by an underground cable to a single shunt-wound dynamo machine, worked by a small agricultural steam-engine of about 25 I.H.P. The current is conveyed from the conductor by means of 2 steel springs, rigidly held by 2 steel bars placed one at each end of the car, and projecting about 6 in. from the side. Since the conducting rail is iron while the brushes are steel, the wear of the latter is exceedingly small. In dry weather, they require the rail to be slightly lubricated; in wet weather, the water on the surface of the iron provides all the lubrication required. The double brushes, placed at the extremities of the car, enable it to bridge over the numerous gaps, which necessarily interrupt the conductor to allow cartways into the fields and commons adjoining the shore. On the car passing one of these gaps, the front brush breaks contact, but since the back brush still touches the rail, the current is not broken. Before the back brush leaves the conductor, the front brush will have again risen upon it, so that the current is never interrupted. When gaps are too broad to be bridged in this way, the driver breaks the current before reaching the gap, the momentum of the car carrying it the 10 or 12 yd. it must travel without power.

The current is conveyed under the gaps by means of an insulated copper cable carried in wrought-iron pipes, placed at a depth of 18 in. At the passing places, which are situated on inclines, the conductor takes the inside, and the car ascending the hill also runs on the inside, while the car descending the hill proceeds by gravity on the outside lines.

From the brushes the current is taken to a commutator worked by a lever, which switches resistance-frames placed under the car, in or out, as may be desired. The same lever alters the position of the brushes on the commutator of the dynamo machine, reversing the direction of rotation. The current is not, as it were, turned full on suddenly, but passes through the resistances, which are afterwards cut out in part or altogether, according as the driver desires to run at part speed or full speed.

From the dynamo the current is conveyed through the axle-boxes to the axles, thence to the tyres of the wheels, and finally back by the rails, which are uninsulated, to the generating machine. The conductor is laid in lengths of about 21 ft., the lengths being connected by fish-plates and by a double copper loop securely soldered to the iron. It is also necessary that the rails of the permanent way should be connected in a similar manner, as the ordinary fish-plates give a very uncertain electrical contact, and the earth for large currents is altogether untrustworthy as a conductor, though no doubt materially reducing the total resistance of the circuit.

The dynamo is placed in the centre of the car beneath the floor, and through intermediate spur-gear drives by a steel chain on to one axle only. The reversing levers, and the levers working the mechanical brakes, are connected to both ends of the car, so that the driver can always stand in front and have uninterrupted view of the rails, which is of course essential in the case of a line laid by the side of the public road.

For calculation, let L be the couple, measured in foot-lb., which the dynamo must exert in order to drive the car, and w the necessary angular velocity. Taking the tare of the car as 50 cwt., including the weight of the machinery it carries, and a load of 20 people as 30 cwt., we have a gross weight of 4 tons. Assume that the maximum required is that the car should carry this load at a speed of 7 miles an hour on an incline of 1 in 40; the resistance due to gravity may be taken as 56 lb. per ton, and the frictional resistance and that due to other causes, say, 14 lb. per ton; giving a total resistance of 280 lb., at a radius of 14 in. The angular velocity of the axle, corresponding to a speed of 7 miles an hour, is 84 rev. per minute. Hence

$$L = 327 \text{ foot-lb., and } w = \frac{2\pi \times 84}{60}.$$

If the dynamo be wound directly on the axle, it must be designed to exert the couple L, corresponding to the maximum load, when revolving at an angular velocity w, the difference of potential between the terminals being the available E.M.F. of the conductor, and the current the maximum the armature will safely stand. But when the dynamo is connected by intermediate gear to the driving wheels only, the product of L and w remains constant, and the 2 factors may be varied. In the present case, L is diminished in the ratio of 7 to 1, and w consequently increased in the same ratio. Hence the dynamo, with its maximum load, must make 588 rev. per minute, and exert a couple of 47 foot-lb. Let E be the potential of the conductor from which the current is drawn, measured in volts, C the current in ampères, and E_1 the E.M.F. of the dynamo. Then E_1 is proportional to the product of the angular velocity, and a certain function of the current. For a velocity Ω, let this function be denoted by $f(C)$. If the characteristic of the dynamo can be drawn, then $f(C)$ is known.

We have then

$$E_1 = \frac{w}{\Omega} f \quad . \quad . \quad (1)$$

If R be the resistance in circuit by Ohm's law,

$$C = \frac{E - E_1}{R} = E - \frac{\frac{w}{\Omega} f(C)}{R};$$

and therefore

$$w = \frac{\Omega (E - CR)}{f(C)} \quad . \quad (2)$$

Let a be the efficiency with which the motor transforms electrical into mechanical energy, then—

Power required $= Lw = aE_1C$

$$= aC \frac{w}{\Omega} f(C)$$

Dividing by w,

$$L = \frac{aCf(C)}{\Omega} \quad (3)$$

It must be noted that L is here measured in electrical measure, or, adopting the unit given by Dr. Siemens, 1 Joule equals approximately 0·74 foot-lb. Equation (3) gives at once an analytical proof of the second principle stated above, that for a given motor the current depends upon the couple, and upon it alone. Equation (2) shows that with a given load the speed depends upon E the electromotive force of the main, and R the resistance in circuit. It shows also the effect of putting into the circuit the resistance-frames placed beneath the car. If R be increased until CR is equal to E, then w vanishes, and the car remains at rest. If R be still further increased, Ohm's law applies, and the current diminishes. Hence, suitable resistances are, first, a high resistance for diminishing the current, and consequently the sparking at making and breaking of the circuit; and secondly, one or more low resistances for varying the speed of the car. If the form of $f(C)$ be known, as is the case with a Siemens machine, equations (2) and (3) can be completely solved for w and C, giving the current and speed in terms of L, E, and R. The expressions so obtained are not without interest, and agree with the results of experiment.

It has often been pointed out that reversal of the motor on the car would be a most effective brake. This is certainly true; but at the same time it is a brake that should not be used except in cases of emergency. For the dynamo revolving at a high speed, the momentum of the current is considerable; hence, owing to the self-induction of the machine, a sudden reversal will tend to break down the insulation at any weak point of the machine. The action is analogous to the spark produced by a Ruhmkorff coil. This was illustrated at Portrush: when the car was running perhaps 15 miles an hour, the current was suddenly reversed. The car came to a standstill in little more than its own length, but at the expense of breaking down the insulation of one of the wires of the magnet coils. The way out of the difficulty is at the moment of reversal to insert a high resistance to diminish the momentum of the current.

In determining the proper dimensions of a conductor for railway purposes, Sir William Thomson's law should properly apply. But on a line where the gradients and traffic are very irregular, it is difficult to estimate the average current, and the desirability of having the rail mechanically strong, and of such low resistance that the potential shall not vary very materially throughout its length, becomes more important than the economic considerations involved in Sir William Thomson's law. At Portrush the resistance of a mile, including the return by earth and the ground rails, is actually about 0·23 ohm. If calculated from the section of the iron, it would be 0·15 ohm, the difference being accounted for by the resistance of the copper loops, and occasional imperfect contacts. The E.M.F. at which the conductor is maintained, is about 225 volts, which is well within the limit of perfect safety assigned by Sir William Thomson and Dr. Siemens. At the same time the shock received by touching the iron is sufficient to be unpleasant, and hence is some protection against the conductor being tampered with.

Consider a car requiring a given con-

stant current, evidently the maximum loss due to resistance will occur when the car is at the middle point of the line, and will then be one-fourth of the total resistance of the line, provided the 2 extremities are maintained by the generators at the same potential. Again, by integration, the mean resistance can be shown to be one-sixth of the resistance of the line. Applying these figures, and assuming 4 cars are running, requiring 4 h.-p. each, the loss due to resistance does not exceed 4 per cent. of the power developed on the cars: or if 1 car only be running, the loss is less than 1 per cent. But in actual practice at Portrush even these estimates are too high, as the generators are placed at the bottom of the hills, and the middle portion of the line is more or less level; hence the minimum current is required when the resistance is at its maximum value.

The insulation of the conductor has been a matter of considerable difficulty, chiefly on account of the moistness of the climate. An insulation has now, however, been obtained of 500 to 1000 ohms per mile, according to the state of the weather, by placing a cap of insulite between the wooden posts and T-iron. Hence the total leakage cannot exceed 2·5 amperes, representing a loss of ¼ h.-p. or under 5 per cent., when 4 cars are running.

Apart from these figures, we have materials for an actual comparison of the cost of working the line by electricity and steam. The steam tramway engines, temporarily employed at Portrush, are generally considered as satisfactory as any of the various tramway engines. They have a pair of vertical cylinders, 8 in. diameter and 1 ft. stroke, and work at a boiler pressure of 120 lb., the total weight of the engine being 7 tons. The electrical car with which the comparison is made, has a dynamo weighing 1½ cwt., and the tare of the car is 32 cwt. The steam-engines are capable of drawing a total load of about 12 tons up the hill, excluding the weight of the engine; the dynamo, over 9 tons, excluding its own weight; hence, weight for weight, the dynamo will draw 5 times as much as the steam-engine. Finally, compare the following estimates of cost. From actual experience, the steam-engine, taking an average over a week, costs—

	£	s.	d.
Driver's wages	1	10	0
Cleaner's do.	0	12	0
Coke, 36½ cwt. at 25s. per ton	3	13	1½
Oil, 1 gal. at 2s. 1d.	0	3	1
Tallow, 4 lb. at 6d.	0	2	0
Waste, 6 lb. at 2d.	0	1	4
Depreciation, 15 per cent. on £750	2	3	3
Total	£8	4	9½

The distance run was 312 miles. Also, from actual experience, the electrical car, drawing a second behind it, and hence providing for the same number of passengers, consumed 18 lb. of coke per mile run. Hence, calculating the cost in the same way, for a distance run of 312 miles in a week—

	£	s.	d.
Wages of stoker of stationary engine	1	0	0
Coke, 51 cwt. at 25s. per ton	2	15	0
Oil, 1 gal. at 2s. 1d.	0	3	1
Waste, 4 lb. at 2d.	0	0	8
Depreciation on stationary engine, 10 per cent. on £500, 11s. 6d.	2	0	4
Depreciation of electrical apparatus, 15 per cent. on £500, £1 ls. 10d.			
Total	£5	19	1

A saving of over 25 per cent.

The total mileage run is very small, on account of the light traffic early in the year. Heavier traffic will tell very much in favour of the electric car, as the loss due to leakage will be a much smaller proportion of the total power developed.

It will be observed that the cost of the tramway engines is very much in excess of what is usual on other lines, but this is entirely accounted for by the high price of coke, and the exceedingly difficult nature of the line to work, on account of the curves and gradients. These causes send up the cost of electrical working in the same ratio, hence the comparison is valid as between the steam and electricity. But it would be unsafe

to compare the cost of either with horse traction or wire-rope traction on other lines. The same fuel was burnt in the stationary steam-engine and in the tramway engines, and the same rolling stock used in both cases; but otherwise the comparison was made under circumstances in favour of the tramway engine, as the stationary steam-engine is by no means economical, consuming at least 5 lb. of coke per horse-power hour, and the experiments were made, in the case of the electrical car, over a portion of line 3 miles long, which included the worst hills and curves, and one-half of the conductor was not provided with the insulite caps, the leakage consequently being considerably larger than it will be eventually.

Finally, as regards the speed of the electrical car, it is capable of running on the level at the rate of 12 miles per hour.

Taking these data as to cost, and remembering how this will be reduced when the water-power is made available, added to such considerations as the freedom from smoke and steam, the diminished wear and tear of the permanent way, and the advantage of having each car independent, it may be said that there is a future for electrical railways. (Dr. Hopkinson.)

Machinery.—Electric engines may be used with advantage in cases where the importance of utilizing power at a distance from an original motor is sufficient to compensate for the loss in converting the power into electric energy, and again in reconverting it into mechanical force at the place where it is to be applied, the total loss in these 2 processes being about $\frac{2}{3}$ of the original force. The dynamo-electric machines employed are the same as those for electric lighting. A machine requiring 2 h.-p. to work it costs about 50*l.*, one requiring 4 h.-p. about 80*l.*, and one 10 h.-p. about 200*l.* The machine for giving out the force is the same as the one that receives it. There is also to be taken into account the wear and tear of the apparatus, and the interest on the capital expenditure.

The principal advantage which may be expected from electric transmission is in the utilization of natural forces, such as water-power or cheap fuel, at distant places. At present, however (1882), copper conductors for transmitting considerable power become costly and inconvenient for distances above 2 miles, and the system is practically limited, as it is seldom that the advantages so obtained compensate for the expense. The most favourable opportunity for using electric engines arises when the generator and conductor are already established for electric lighting. A small conductor $\frac{1}{8}$ in. diameter will not only suffice for numerous lights, but would afford 1 or 2 h.-p. for a motor, and smaller motors suitable for a sewing-machine or other domestic purpose can be purchased for 3*l.* to 10*l.* Electric science is advancing so rapidly that the present difficulties are likely to be overcome, and the cheapness with which large motors can be worked as compared with numerous small ones will compensate for considerable loss in distribution and reconversion, if the difficulties and expenses of long conductors be removed. A motor of $\frac{1}{2}$ h.-p. weighs less than 40 lb., and occupies very small space. Forms suitable for driving tricycles can be attached beneath the seat. At the Agricultural Show at Bar-le-Duc, France, in May 1880, an electromotive machine was exhibited, suitable for agricultural use. A large field was successfully ploughed with one of Howard's double-furrow ploughs worked by it.

The experiment of Deprez at Munich gives much information for future use. With machines of the type described by him, 2000 volts is too high an electromotive force to employ. The reason is that it is impossible to prevent the contact of the brushes from being sometimes accidentally broken. In such a case it was found that the electromotive force developed by the extra current is sufficient to ruin the insulation. Another matter deserving of attention is the relative size of the generator and motor. Deprez employed 2 machines of equal

size. This slightly simplifies the theory, but it is certainly not the most advantageous arrangement, and we are much in want of accurate measurements on this head. The Deprez experiment at Munich was, commercially, a failure. Since then Deprez has been occupied with experiments of a far more practical nature, with a line of 160 ohms resistance. In the latest experiments, where the effects of friction were deducted, a return of 47½ per cent. was obtained, and 4·4 h.-p. of work was actually given off by the motor. If a fall of water be used as the motive power, we can install a turbine and dynamos which shall transmit 6 h.-p. through a resistance of 12 ohms, at a cost of 200*l.*, omitting the unknown cost of the conductor. If this power were used in a place where coal costs 20*s.* per ton, the cost of fuel for 6 h.-p. would be about 60*l.* per annum. The interest and depreciation on the boiler and steam-engine would be about 30*l.* per annum, making in all 90*l.* per annum, exclusive of wages. Electrically transmitted, the interest on plant, at 15 per cent., would be 30*l.* per annum, exclusive of wages. This difference of 60*l.* per annum, after deducting from it the interest and depreciation of the conductor, is so enormous, that it is easy to see what a large saving would be effected in any installation where there is a large consumption of power. There are many factories where it is essential to use a high-priced coal, but if the power could be conveyed electrically from a distance of a few miles, an immense saving would be effected by employing a cheaper kind of coal. When water-power is used, it often happens that the cables can be conveyed along the bed of the river. This preserves the insulation, and keeps the conductor cool, so preventing the usual increase of resistance by heating. In some towns, notably Sheffield, the whole of the water supplying the town comes from reservoirs at a great height. The very large quantity of energy of this water is at present absolutely wasted. At the site of the Severn Tunnel is a width of river of 2½ miles, where the average rise of tide is 50 ft. If the average rate of flow across this section were 1 mile per hour, we could utilize 100,000 horse-power, and the market value of that power is something like 1,000,000*l.* per annum, which is now allowed to be wasted. It is worthy of the most serious consideration whether it would not be worth while to erect the enormous engineering works which would be required to utilize this wasted energy, or rather a portion of it, even assuming the interest and depreciation on the turbines and dynamos to be at the rate of 2*l.* per annum per horse-power (and it would be far less than this for a large installation). (Prof. Forbes.)

Phonographs.—The phonograph is an instrument by which sounds can be imprinted on soft metal, such as tinfoil, and reproduced with distinctness and accuracy of tone any number of times. It consists of 3 parts: a receiver, a recorder, and a reproducer.

The receiver consists of a curved tube, one end of which is fitted with a mouthpiece, and the other end closed by an exceedingly thin metallic plate or diaphragm, which vibrates with the least sound. On the centre of the outer side of this metallic diaphragm is a small blunt steel pin. The recorder is a brass cylinder 4 in. long and 4 in. in diameter, with a continuous V-shaped groove cut into it from end to end, like a large screw; 2 pins 4 in. long are fixed in the ends of the cylinder, one of which is cut with a screw thread, corresponding to that of the V-groove in the cylinder, and these pins are fitted into appropriate bearings, 8 in. apart. By turning a handle fixed on to one of the pins just referred to, the cylinder is not only rotated, but traverses from one support to the other. In using this instrument, the recorder is covered with a sheet of tinfoil, and is placed in front of the vibrating diaphragm of the receiver, the blunt pin of which just touches the surface of the tinfoil, and is opposite the commencement of the groove of the brass cylinder. If now a person speaks into the mouth-

piece of the receiver, and the handle of the recorder be turned, a spiral series of indentations will be made on the tinfoil by the pin of the vibrating diaphragm, these indentations corresponding to the groove in the brass cylinder under the tinfoil. The sounds that have been uttered are now recorded on the tinfoil. The reproducer, which forms the third part, consists of a conical metallic drum, having its larger end open; the smaller, which is about 2 in. in diameter, being covered by a sheet of paper stretched tight like a drum. In front of this paper diaphragm is a light, flat steel spring, held in a vertical position, and from the end of which a blunt steel point projects. The spring is connected with the paper diaphragm by means of a silken thread, which is placed just sufficiently in tension to cause the outer face of the diaphragm to assume a slightly convex form. In order to reproduce the sounds received on the tinfoil, the receiver is placed in front of the "reproducer," so that the blunt pin is just over the first indentation; the handle of the receiver is turned in a reverse direction to what it was before, and this causes the spring of the reproducer to vibrate. The movements of the spring are communicated to the paper diaphragm by the silken thread, and the words spoken into the receiver are heard issuing from the open end of the reproducer. (Dyer.)

It must not be supposed that all the tinfoil used for phonographic registration is equally good. The foil must be of a definite thickness, and combined with a certain amount of lead. That which is used for wrapping chocolate, and indeed all foil of French manufacture, is too thin and too exclusively made of tin to produce good results. The relative proportion of lead and tin has not yet been defined, and the selection of foil has been made empirically; but as the use of the phonograph becomes more general, this proportion must be ascertained, and it may easily be done by analysing the composition of the foil which gives the best results.

The arrangement of the tracing-point is also of much importance for the successful action of the phonograph. It must be very slender and very short (not exceeding 1 millimètre in length), so as to register distinctly the smallest vibrations of the vibrating disk without deviating from the normal direction of the cylinder, which might be the case, if it were long, on account of the unequal friction exerted on the tinfoil. It must also be made of a metal which has no tendency to tear the metallic sheet. Iron appears to combine most of the conditions demanded. (Hedges.)

Shelford Bidwell gives the following description of how to construct a phonograph. He says the most important part of it is the cylinder. This, in his phonograph, is a hollow brass casting, $4\frac{1}{2}$ in. long and $4\frac{1}{2}$ in. in diameter. It is mounted upon an iron spindle $\frac{3}{4}$ in. in diameter and 16 in. long, at one end of which is a winch handle. Upon that part of the spindle which lies between the handle and the cylinder, a screw is cut, having 8 threads to the inch. The other end of the spindle is left plain. The cylinder having been turned perfectly true, a screw is cut upon its surface of exactly the same pitch as the screw upon the spindle—*i.e.* 8 threads to the inch. The depth of the spiral groove thus formed is $\frac{1}{15}$ in., and its breadth is $\frac{1}{16}$ in. It is better to cut it square, and not V-shaped. Two brass bearings for the spindle are made of the following dimensions—length, $2\frac{1}{4}$ in.; thickness, $1\frac{1}{8}$ in.; height, $1\frac{1}{2}$ in. One of these has an inside screw corresponding to the screw upon the spindle. Each bearing has 2 holes for screwing it to the support. The cylinder, spindle, and bearings being completed, 10 pieces of wood must be prepared as follows:—

A is 12 in. × $9\frac{1}{2}$ in. × $1\frac{1}{8}$ in.

B is 3 in. × 3 in. × $1\frac{1}{8}$ in.

C is similar to B.

D is $5\frac{1}{2}$ in. × $5\frac{1}{2}$ in. × $\frac{1}{2}$ in., and has a circular hole, $2\frac{3}{4}$ in. in diameter, cut in its centre.

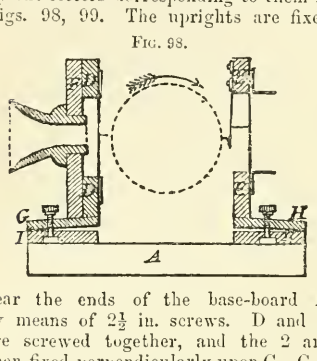
E is similar to D.

F is $5\frac{1}{2}$ in. × $5\frac{1}{2}$ in. × $\frac{1}{2}$ in., and has a hole, 1 in. in diameter, in its centre.

G is $5\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{1}{2}$ in.
H is similar to G.
I is 8 in. × $2\frac{1}{2}$ in. × $\frac{1}{2}$ in.
K is similar to I.

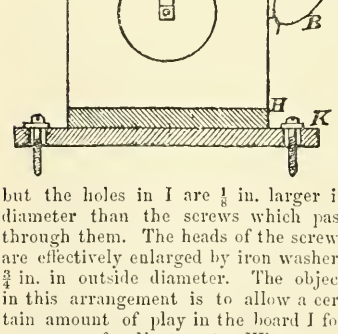
There are 2 upright supports for the bearings. The position is indicated by the letters corresponding to them in Figs. 98, 99. The uprights are fixed

FIG. 98.



near the ends of the base-board A by means of $2\frac{1}{2}$ in. screws. D and F are screwed together, and the 2 are then fixed perpendicularly upon G. G is joined to I by a pair of hinges. The 2 ends of I are screwed to the base-board,

FIG. 99.



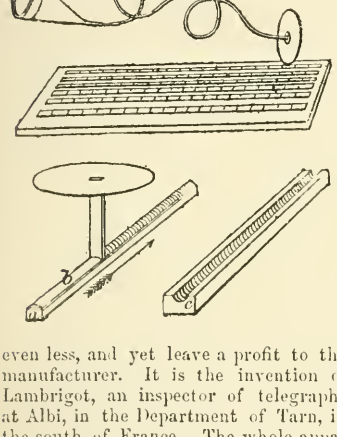
but the holes in I are $\frac{1}{8}$ in. larger in diameter than the screws which pass through them. The heads of the screws are effectively enlarged by iron washers $\frac{3}{4}$ in. in outside diameter. The object in this arrangement is to allow a certain amount of play in the board I for purposes of adjustment. When properly adjusted, the screws may be tightened, and the board firmly fixed in position. E is attached perpendicularly to H, and made rigid with 2 small triangular pieces, not shown. H is hinged to K, and K is fixed to the base in exactly the same manner as I. Through the middle of I is passed a brass screw-bolt, the square head of which is fixed in I. The screw goes through an elongated hole in G, and is fitted with a round milled brass nut. It is well to place a washer under the nut. Screw-bolts of this description are used for fixing the expanding bodies of ordinary photographic cameras, and may be had of any optician. H and K are fitted with a similar bolt. Two rather stiff pieces of steel spring are attached to the ends of I, and extend for a little distance underneath G. These springs tend to separate G and I, or rather to cause G to turn backwards, like the lid of a box when opened. The nut, of course, works against the springs. When the nut is screwed up tight, G and I approach, and may be made almost to touch each other. When the nut is loosened, the spring causes G to rise. Very delicate adjustment is thus rendered possible. H and K are fitted with similar springs for a similar purpose. The diaphragm which receives the voice is fixed over the circular hole in D, as shown in Fig. 98. It consists of a circular plate of very thin iron 4 in. in diameter. Ferrotype plate will answer the purpose very well, but thin charcoal iron is better. It is, however, possible to have the iron too thin. About two-thirds the thickness of an ordinary ferrotype plate is the best. The point is made from a knitting-needle about $\frac{1}{25}$ in. in diameter, which must be very hard—one which can be bent is of no use. The original point had better be broken off, and a new one ground upon an oilstone. For this purpose, the needle is held at an angle of about 30° with the stone, and is constantly turned round. The point, having been made tolerably sharp, is polished and cut off with a file. The part so cut off is $\frac{3}{16}$ in. long. This has now to be attached perpendicularly to the centre of the diaphragm, and the method of doing so is as follows:—The diaphragm is laid upon a sheet of glass,

and a little spot in its centre—about $\frac{1}{8}$ in. in diameter—is scraped clean with a knife. This must be done carefully and gently, or a bulge will be produced. The fragment of knitting-needle is then taken up with pliers, and its blunt end, having been moistened with soldering fluid, is held above the flame of a spirit-lamp, and touched with a piece of tin-foil. With a little manipulation, a small bead or globule of tin may thus be made to adhere to the end. The scraped spot on the diaphragm is now moistened with soldering fluid, and the diaphragm is supported at some distance above a small spirit flame. The ring of a retort stand forms a convenient support. The butt end of the point, with tin globule attached, is then applied to the scraped spot with pliers. In a few seconds the globule melts, when the lamp is instantly removed, and the point manipulated with the pliers, so as to be perfectly upright when the tin hardens, which will take place in a few seconds more. The point will then be found to be firmly attached. The diaphragm and point must, after this operation, be thoroughly washed with soap and water, and slightly oiled—otherwise they will rust. The only precaution to be observed is to apply no more heat than is just necessary for melting the tin. Too much heat will warp the disc, and, if it is a ferrotype, blister the japan. The soldering fluid consists of equal parts of hydrochloric acid and water, in which is dissolved as much zinc as possible. A pile of books will be found useful for steadying the arm while manipulating the point. The diaphragm is fixed in its place by means of a brass flange (like a camera flange), 4 in. in outside diameter, with a $2\frac{3}{4}$ in. opening. Four screws are used. The second diaphragm is made of parchment paper, like that used for covering jam-pots. It is 4 in. in diameter, and is gummed over the hole in E on the side remote from the cylinder (see Fig. 98). When the gum is dry, the diaphragm is moistened, and again allowed to dry, when it will be found to be as tight as a drum. The second point is exactly like the first, though it may with advantage be a trifle sharper. It is not attached directly to the paper diaphragm, but to a steel spring, which may be seen in Figs. 98 and 99. This is a piece of mainspring $\frac{5}{16}$ in. wide and $2\frac{7}{8}$ in. long. It is fixed above the hole in E by means of 2 strips of brass, as shown in Fig. 99, and is just so much bent that the end of it, when free, is $\frac{5}{8}$ in. distant from the plane of E. The power of this spring may, however, be varied within considerable limits without appreciable difference in its performance. The point is fixed to the spring in the same manner as to the iron disc, but the same care as to over-heating is not requisite, and the operation is consequently easier. Before the spring is screwed in its place, a loop of sewing silk is attached to the centre of the paper diaphragm by means of a piece of court plaister $\frac{1}{4}$ in. square (see Fig. 99, where A is the piece of plaister, B the loop). The length of the loop must be such that when it is drawn over the spring just above the point, the end of the spring may be nearly in the plane of E. The spring is thus caused to draw the paper drum even tighter than before, and its inner surface is rendered slightly convex. Another flange carrying a short rim or spout is now screwed round the paper drum. A paper resonator is made to slip over the short rim or spout. It is a cone made of 2 or 3 thicknesses of stout drawing-paper. Its length is 18 in.; diameter at small end, $2\frac{3}{4}$ in., and at large end, 7 in. The resonator greatly reinforces the sound when the phonograph is speaking. A wooden mouthpiece like those used for speaking-tubes is inserted into the hole F. The instrument is now complete, but it will require careful adjustment before it can be used. In the first place, the screws which attach I to the base must be loosened, the milled nut on G screwed up tight, and the piece I shifted about until the point on the iron disc is exactly in the middle of one of the grooves on the cylinder, and barely touches the bottom of it. Then the screws must be tightened, and this

part of the apparatus is finally adjusted. The same process is repeated on the other side, but in this case the adjustment is not quite final, as will hereafter be seen. The next thing is to procure suitable tinfoil. This should be rather stout—about 15 sq. ft. to the lb.—and should be cut into pieces 14½ in. by 4½ in. Before putting a tinfoil upon the cylinder, the 2 nuts are removed, and the diaphragms turned back out of the way. A little gum brushed along one end of the tinfoil will be sufficient to keep it firmly in its place; the join must be carefully smoothed. The diaphragms are then turned back to their places, and the nuts screwed on. The nut on G is screwed up just far enough to cause the point on the iron diaphragm to touch the tinfoil very lightly. The handle is then turned about ¼ rev., causing the point to make a short scratch on the tinfoil. The nut on G is thereupon loosened, withdrawing the point from the tinfoil, and the nut on H being screwed up, another turn is given to the handle. If the scratch thus produced exactly coincides with the former one, well and good; if not, the screws attaching K to the base must be loosened, and K shifted about until absolute coincidence is attained. The utmost accuracy on this point is essential. The instrument may now be considered fit for use. Loosen the nut on H, so that the point on the spring may be well away from the tinfoil, and screw up the nut on G, so far that the point on the iron diaphragm may score a well-defined furrow on the tinfoil when the handle is turned. Turn the handle with as great regularity as possible, at the rate of about 1 turn per second, or a little slower. Speak loudly and distinctly into the mouthpiece, putting the mouth as near as possible to it, without actually touching. When you have finished, withdraw the point by loosening the nut, turn the handle backwards until the cylinder is in its original position, and screw up the second nut until the second point presses lightly but steadily upon the bottom of the furrow. Then put on the paper resonator, and turn the handle at the same speed as before. If the adjustments are perfect, the result will be astonishing. It will be observed that this instrument has 2 diaphragms, whereas Edison's latest has only 1, which does both the receiving and the speaking. Bidwell made many experiments with the object of dispensing with 1 of the diaphragms, but never, under any circumstances, obtained so good results with 1 as with 2. Preece told the Physical Society that the employment of only 1 was a "retrograde step." Bidwell does not believe that iron and parchment-paper are the best possible materials for the diaphragms, though they are better than any others tried. The great fault in the iron appears to lie in its tendency to resound forcibly to certain overtones in certain vowel sounds. Bidwell tried to overcome this by coating the diaphragm with indiarubber, but with no great success. He thinks, however, that a ring of indiarubber between the diaphragm and the flange has an undoubted effect in diminishing the nuisance. The steel spring is subject to independent vibrations of a similar nature. These may be damped by causing a piece of soft indiarubber to press lightly upon it at a point about ½ in. below the lower strip of brass. He also found it an advantage to wrap indiarubber round the top of the spring before screwing it on. He believes that the mouthpiece of a telephone would give better results than that of a speaking tube. A long resonating mouthpiece like that which Edison first used is worse than useless. The point on the steel spring should be made to turn very slightly upwards instead of being perpendicular. In the latter case, it is liable to produce a squeak something like that of a slate-pencil when drawn upright across a slate. If the points are too sharp, they will cut and scrape the tinfoil; if too blunt, the articulation will be muffled. After the points have traversed the cylinder 200 or 300 times, they will require sharpening. This can be done with a small oil-stone, without removing them. (*Eng. Mech.*)

The very simple apparatus illustrated in Fig. 100 is a speaking phonograph that can be made and sold for 6*d.*, or

Fig. 100.



even less, and yet leave a profit to the manufacturer. It is the invention of Lambrigot, an inspector of telegraphs at Albi, in the Department of Tarn, in the south of France. The whole apparatus consists, first, of a hollow cone of pasteboard about 1½ in. in diameter, whose apex is connected to the centre of a similar-sized pasteboard disc by means of a leaden wire about 16 in. long; and second, of a small board or tablet, on which is fixed 1, or a larger number of short lengths of leaden wire, each of which bears upon its upper surface a phonographic embossed record corresponding to a certain word or sentence, by which it was originally produced by a process to be described further on.

To those who are familiar with the construction of the phonograph in the form in which it was first shown in this country, it would appear necessary, in order to reproduce the sounds recorded on the tablet, for the edge of the disc to be held in an annular frame so as to convert it into a diaphragm, and for its centre to be thrown into vibration by means of a point or style projecting from it and drawn over the undulatory surface of the record. But the method of using the apparatus is far simpler than that; all that is necessary is to hold the paper cone against the ear with one hand, and with the other to take hold of the cardboard disc, drawing its edge along the record with a steady scraping motion, and the mechanical vibrations thus set up in the disc being communicated by the wire to the conical earpiece which serves as a resonator and concentrator, produce in the organs of hearing the sensation of the articulate sound by which the markings on the leaden record were originally produced. We should have thought that a stout thread or a lighter wire would have formed a more efficient as well as a cheaper connection for the purpose than the leaden wire, but we are informed that Lambrigot has found the lead to answer the purpose better than anything else; it does not require to be kept stretched between the cone and the disc, and being of a very inelastic nature, it does not spring about and produce disturbing sounds by clashing against itself or against neighbouring objects. Again, it would naturally be expected that the earpiece would be more perfectly adapted to its purpose if it were in the form of that used in the ordinary thread telephone; that is to say, if it consisted of a cylindrical cardboard box closed at one end with a stretched paper diaphragm, to the centre of which the connecting wire was attached; but simple as it is, this would undoubtedly be a more complex form of construction than the cardboard cones, and would be far more liable to be destroyed by the weight of the connecting wire. The employment of cardboard as the material of which the principal parts of the apparatus are constructed, is, in the case of the cone, for cheapness, and in that of the disc, partly for cheapness, but chiefly to protect the markings on the leaden record from being destroyed, as they soon would be if a harder material than card were employed.

The most interesting point connected with this very simple apparatus is the method by which the leaden records are produced, which is as follows:—The upper surface of a rectangular prism of

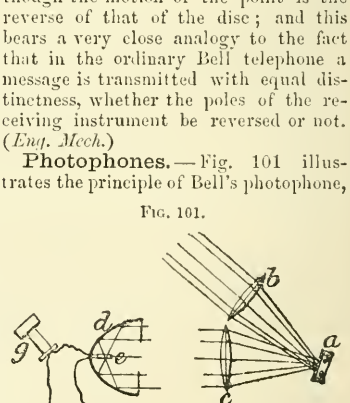
glass, or other hard and rigid material, is thickly coated with stearine wax, which is then scraped into a convex form, as shown in the diagram, in which *a* represents the glass bar and *b* the convex coating of stearine. This bar is then fixed into a simple phonographic instrument, which, by means of a screw or other mechanical contrivance, traverses it at a suitable speed below a diaphragm. This diaphragm is rigidly held around its circumference by an annular framework (not shown in the diagram), and is in every respect exactly similar to the diaphragm of an ordinary phonograph. To the centre of this diaphragm is attached a thin flat plate, whose lower end is cut out to a concave curve, to fit the convex surface of the stearine *b*. When all is properly adjusted, and the temperature is so arranged as to give to the stearine surface the proper degree of hardness to ensure the best results, the handle of the instrument is turned, and at the same time words are spoken against the diaphragm, which immediately set up in it vibrations, which are communicated to the plate or style. While this is moving up and down, following the vibrations of the diaphragm caused by the voice, the stearine coating of the bar *ab* is steadily drawn in the direction of the arrow below the vibrating bar, receiving from it a phonogram similar to that produced on the tinfoil of an ordinary phonograph.

The stearine bar is then coated with a fine surface of graphite, so as to give to it an electrically conducting surface, and it is then electro-plated with copper by the ordinary process. Out of the copper coating so formed the stearine is removed, and a rigid backing of lead or other metal having been run over the outside convex surface of the copper, a firm copper-lined matrix or mould is formed, the whole presenting the appearance shown, and consisting of a rectangular block having along the middle of one of its faces a semi-cylindrical groove *c* of copper, which bears upon its surface certain raised striations corresponding to the depressions which were made by the diaphragm on the surface of the stearine. Into this groove is laid a piece of lead wire about 3 or 4 millimetres in diameter, and the two being put into a press and squeezed together, the surface of the lead wire receives a permanent impression which is an exact reproduction of the original impression made upon the stearine bar. From one copper matrix a very large number of lead impressions may be made, and we are told that the whole process can be gone through, and lead wires, each containing the record of a short sentence, can be made and sold with a profit for ½d. each.

It is an interesting fact that if a small stick of wood, such as the stem of a common match, be substituted for the disc, and its end be drawn along the copper groove of one of the matrix moulds, articulate speech is communicated equally well to the earpiece, although the motion of the point is the reverse of that of the disc; and this bears a very close analogy to the fact that in the ordinary Bell telephone a message is transmitted with equal distinctness, whether the poles of the receiving instrument be reversed or not. (*Eng. Mech.*)

Photophones.—Fig. 101 illustrates the principle of Bell's photophone,

FIG. 101.

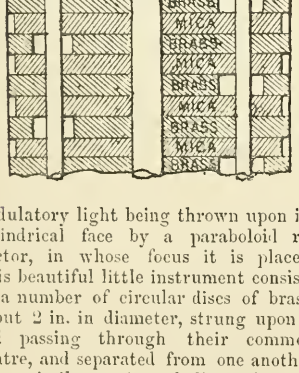


and shows one of the most successful arrangements. A beam of light from any source is concentrated on the diaphragm *a* by the lens *b*, and the diaphragm of silvered mica or glass capable of reflecting the light is placed in such a position in relation to the lens *b*

as to project the light along a line joining the axes of the lens *c* and of the parabolic reflector *d*. The lens *c* renders the divergent rays of light parallel, and the parabolic reflector concentrates the light upon the selenium cell *e*. The selenium forms a part of an electric circuit, which includes the battery *f* and receiving telephone *g*. A sound made in the vicinity of the transmitting instrument vibrates the diaphragm *a*, and undulates the beam of light projected through the lens *c*, and the consequent variations in the intensity of the light concentrated on the selenium by the parabolic reflector, changes the electrical conductivity of the selenium, and renders the electric current undulatory. This current affects the receiving telephone in the same way as it would be affected in an ordinary telephonic circuit, and the sounds made in the transmitting instrument are reproduced in the telephone.

Fig. 102 shows the cylindrical form of selenium cell adopted, the rays of

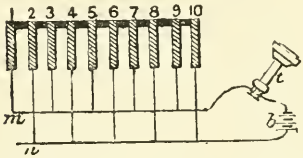
FIG. 102.



undulatory light being thrown upon its cylindrical face by a paraboloid reflector, in whose focus it is placed. This beautiful little instrument consists of a number of circular discs of brass, about 2 in. in diameter, strung upon a rod passing through their common centre, and separated from one another by a similar series of discs of mica, whose diameter is slightly smaller than that of the brass discs, so as to form with the latter (when the whole is built together as a cylinder) a number of grooves around its cylindrical surface. The discs are held firmly together by nuts and bolts passing through them, 2 of which are shown in the diagram, and which form the connecting screws for placing the instrument in circuit with a pair of telephones and a battery. Upon reference to Fig. 102 (which is only a diagram explanatory of the arrangement of circuits, and does not represent the construction of the instrument or the proportion of its parts), it will be seen that every alternate disc of brass is in metallic connection with the upper bolt, but is insulated from the lower bolt, and *vice versa*. In other words, if all the brass discs were numbered consecutively from one end of the series to the other, all the discs marked with even numbers are connected to the lower bolt and insulated from the upper, and all the uneven-numbered discs are in contact with the upper bolt, but insulated from the lower. The grooves formed around the cylindrical surface are filled in with selenium by the following simple process: the cylinder is first heated to a temperature somewhat above that of the fusing-point of selenium, and, while hot, a stick of selenium is rubbed over its surface, filling up the grooves and covering the edges of the brass discs. The cylinder is then put in a lathe, and the selenium is turned off until the edges of the brass discs are bared. Before being sensitive to light, however, the selenium has to be annealed by first heating it until signs of fusion begin to show themselves; when the heat is removed, the fused portions recrystallize, and the selenium is thereby rendered both sensitive to light and a conductor of electricity. Prof. Bell states that the whole process of annealing occupies only a few minutes. Fig. 103 is a diagram in which the connection of the brass discs with the external or telephonic current is more clearly shown. Here it will be seen that the discs numbered 1, 3, 5, 7, and so on, are connected to one terminal of the telephone *t* by the wire *m*, while

the even discs 2, 4, 6, 8, &c., are in connection with the other terminal through the wire *n* and battery *b*. Upon examination of the diagrams, it will be

FIG. 5.



seen that while the surfaces of contact between the selenium rings and the brass discs are increased to a maximum by reason of their large diameter, which also ensures a maximum of sensitive surface, the resistance of the whole photopile is reduced to a minimum, not only by the method of making the circuits as shown, but by the large sectional area of conducting material presented by the annular form of the selenium.

The transmitting instrument of the photophone is shown in Fig. 104, and

FIG. 104

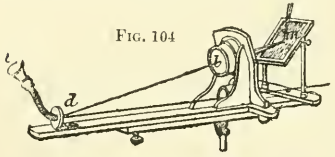
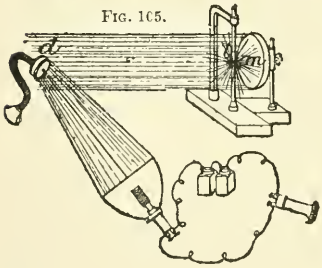


FIG. 105.



consists of a long board mounted upon a firm support (with suitable adjustments for directing it, within certain limits, in both altitude and azimuth), to which are attached the various parts of the apparatus: *o* is the mouthpiece with its reflecting diaphragm *d* of silvered glass or mica, and *m* is the mirror by which a ray of light from the sun or any other powerful source may be projected on to the diaphragm *d* by the condensing lens *l*, below which is fixed another lens for the purpose of parallelizing the beam after reflection from the silvered diaphragm, and projecting it to the distant station, where it is received by the paraboloidal reflector of the receiving instrument, in the focus of which is placed one of the cylindrical photopiles such as described, and in circuit with the latter is placed a pair of telephones and a voltaic battery, which in Prof. Bell's experiments consisted of 9 Leclanché cells.

Prof. Bell made a series of photophonic experiments in Paris, using the electric light as his source of illumination, and it is an interesting fact—although one which might have been expected from the results obtained in his earlier experiments—that the irregularities and vibrations, which are well-nigh inseparable from the light emitted by the electric arc, produce their effect in the telephone as an unceasing murmur, while at the same time articulate speech is heard superposed, as it were, upon the "voice" of the arc.

Fig. 105 is a diagram illustrating the arrangement of apparatus with which Prof. Bell worked in Paris. *l* is the electric lamp, the arc of which is in the focus of a paraboloidal silvered reflector *m*, by which the divergent rays emanating from the arc are condensed and projected as a parallel beam to the reflecting diaphragm *d*, by which a certain small proportion of them is reflected to the receiving instrument through a distance of nearly 50 ft., as shown in the figure. From this diagram it will be seen that a very large proportion of the light projected by the lamp reflector does not fall upon the diaphragm at all, but notwithstanding this loss, highly satisfactory results were obtained in the transmission of articulate speech, and Prof. Bell is of opinion that effects equal to those obtained with sunlight would be produced by means of an

electric lamp suitably arranged so as to utilize the whole of the light radiating from the arc. (*Engineering.*)

Storage.—The following observations on the electrical storage of energy are gathered from Prof. Oliver Lodge's Cantor lecture on "Secondary Batteries and the Electrical Storage of Energy."

Methods of storing energy are very numerous, and may be divided into 2 classes, mechanical and chemical. Under the first class come the raising of weights, as by the pumping of water into a reservoir; and that is a very efficient method of storing energy for future use, as a large proportion of the energy can be made available. Another mechanical method is by the coiling of springs, or producing strain in an elastic body by twisting—a form of storage familiarly exemplified in winding up a watch. A third form of mechanical storage is by charging a Leyden jar. The old idea of the action of a Leyden jar was that it was a chemical action; but that is not the case. What is being done in charging a jar is producing a strain on the molecules of the glass vessel. If the strain be carried too far, the glass will burst under the internal tension, producing a disruptive discharge, and overcoming the molecular resistance. There are also various chemical methods of storing energy. One class is represented by gunpowder, dynamite, and other explosives, though it must be confessed that this use of the term chemical storage is somewhat questionable in the case of gunpowder, for in it are combined substances not in themselves explosive, which in combination yield great energy when a light is applied to them. The smelting of metals is a better example of chemical storage. By the melting of zinc is produced a material which can be employed for evolving energy in a common battery. Then we have the energy of sunlight stored on a gigantic scale by radiation upon vegetable substances, and this stored solar energy can be reproduced by the burning of coal either directly or as gas. This form of energy is utilized as a mechanical power in the well-known gas-engine, in which a mixture of coal gas and common air produces a mild form of explosion which furnishes an available energy. The amount of energy obtained for a given quantity of gas by this electro-chemical decomposition is not very great; other gases are known which have far more explosive power in small quantities than a mixture of coal gas and air. Thus a mixture of oxygen and hydrogen, if brought together, will decompose and explode with far greater violence than coal-gas and air, and thus can be made to store and reproduce a larger amount of energy. Many persons are directing attention to the second example of decomposition of gases as a possibly practicable method of storing and reproducing energy, and Prof. Lodge is not quite sure but that it will be rendered useful in the future: whether it ever will be found an economical manner of utilizing energy remains to be seen; most probably not. Even in a test-tube the gas is too much confined to evolve much energy. These forms of storage by mechanical and chemical means may be distinguished as proper or improper, and in more exact language, as homotropic and heterotropic.

Passing next to consider the direct storage and reproduction of electric energy, Dr. Lodge points out that this can only be effected by the use of 2 conducting surfaces or plates, one of which must be different either in material or in action from the other. One of these plates must be attackable by electric energy, and the other not so attackable. Any difference in the attackability of the 2 plates will cause them to act as a battery—and the action may be produced either by using plates of different metals, or by acting in a different manner on 2 plates of the same material. In a platinum cell, one plate is oxygenized and the other hydrogenized. The hydrogenized plate is the one attacked, and the oxygenized plate is not attacked; the current passes through the cell from one plate to the other till the gas stored on the plates, *i.e.* the energy, is consumed, an event

which happens very soon. A secondary battery or store of electric energy consists of a reservoir connected by wires on the one side with a plate of source, and on the other with a plate of use, and some switch arrangement is needed to connect or disconnect it as required with the plates of source and use. A simple example of a secondary battery consists of a store or glass cell containing dilute sulphuric acid, in which 2 plates of lead are partially immersed, and these are connected by wires at will by a switch, either with a bell or a galvanometer, or with both. After the plates have been immersed a few seconds, it is found that they are saturated with electricity, as shown by the escape of gas in bubbles, and any attempt to store energy by continuing the current beyond that point is sheer waste. By switching it on to a bell and galvanometer, it can be seen how transient the energy in such a cell is, as it only rings the bell or deflects the needle for a few seconds, and the current is then exhausted, the cell needing a few minutes' rest to recover its energy. This is because the 2 plates cannot retain the gas; what is wanted is a plate to hold the oxygen, and become oxidized. This is the principle of Grove's gas battery. In Ritter's secondary piles, oxidized metals are employed; but it is necessary that the oxide of the metal used for plates shall not be soluble. Lead fulfils this condition, not being soluble, and is therefore a good material for plates, but it absorbs more than it ought. Silver and manganese, like lead, have a peroxide; but lead is better suited for use as plates than other metals, because its peroxide is less soluble in dilute sulphuric acid, and hence one can store in leaden plates the largest quantity of electric energy.

In defining the positive and negative poles, Dr. Lodge calls that the positive plate which is oxidized, and from which the current enters the store; and that the negative which is hydrogenized, and by which the current leaves. In other words, the oxide plate is plus or positive, and the hydrogenized plate minus or negative. Whether tested by duration of ringing or deflection of needle, the negative plate is the first to fail. This was the condition of the Ritter secondary pile before the days of Planté. The improvement introduced by the latter worker consisted in providing a reducible plate. The lead in itself is irreducible. Planté achieved his object by the simple process of reversing the action in the cell, converting the positive into the negative plate, and *vice versâ*, so that the hydrogenized plate became oxidized. The peroxide penetrates deeper and deeper into the plates as they are successively used as positives, and by repeated reversals their surfaces ultimately come to have a porous spongy condition—a state which takes a month or two to attain. Returning to a consideration of the failure of the negative plate: on taking a piece of amalgamated lead and withdrawing it upon exhaustion, the mercurized surface of the plate is seen to be dimmed over by a glaze. This glaze, it can be further shown, is sulphur, and the early failure of the negative plate is due to the formation of a coat of sulphate of lead. The film is extremely thin, imperceptible on ordinary lead, yet is sufficient to stop the current. That this is the correct explanation is shown by wiping off the film by rubbing the plate on a cloth, when the current again passes till the sulphate has been redeposited. At first sight it would seem best to employ a metal for the plates, of which the sulphate was soluble; but that would not answer, for the positive plate, when the current was reversed for the peroxide, would also be dissolved, and the peroxide deposited on the positive plate conducts electricity, whereas the sulphate of the negative plate does not.

The improvement introduced by Faure, was to get reducible plates without the great number of preliminary reversals necessary under Planté's system. Planté provided oxidizable plates, but their oxidizability did not extend to any great depth, and most of the force escaped. Faure decided to coat his plates with some porous peroxide, and found that minium, red-lead, and

litharge were suitable for the purpose. By this means a large absorbent surface was provided, and the waste occasioned by the giving off of gas from the cell was delayed, thus increasing the storage capacity of the cell by that interval. The peroxide coat sponged out till all was peroxidized, and so there was no discharge till the plate was full. For the positive plate it was found best to use minium, and for the negative red-lead as a coat. If the quantities of coats and liquid were properly adjusted, both plates would be filled together; but, as a matter of fact, this was not attained. That was the Faure principle, in which there were no reversals of current, and the economy in time over the Planté or reversing system could be estimated from the fact that a Faure cell was prepared in a week, whereas the Planté cell took 2 or 3 months to fill, while there was no essential difference in the results of the 2 forms of storage. The time and expense of production were thus greatly diminished under the Faure system. But in practice it was not found easy in the Faure cells to make the coating adhere to the plates for any length of time. The red-lead or minium had no affinity for the lead steeped in the liquid, and speedily peeled off, and the difficulty arose, how could the 2 substances be kept together. The first attempt at a solution was to place porous material between the plates, and then the composition was literally tied on to the plates by bands of cloth. But this did not give a good chemical contact with the plate, and another difficulty was that the cloth was rapidly attacked and decomposed by the dilute sulphuric acid. To prolong its life, the best trousering cloth was used, and this proved very expensive, and did not last long nor give a good contact; besides this, the coats and plates would not bear such shaking as they would sustain in transit by railway.

A further improvement was devised, and consisted in putting the oxidizing coating into perforations or interstices of the metallic plates themselves. This was hit upon by Swan and Sellon almost simultaneously, Swan being actually the first in point of time. In the perfected battery known as the Faure-Sellon-Volckmar, the lead becomes a grid filled with an oxidizable composition. First of all, cast-iron moulds are prepared, scored all over like a gridiron with a network of straight channels. Two of these matrices are put together, and the molten lead is poured into them; rectangular pierced sheets of lead are cast as the result. These framed grids are then filled with composition—litharge for the positive and red-lead for the negative plate, the composition being made into a pulp with diluted sulphuric acid, and run in. Though the plates may be somewhat dusty, the composition adheres well to them, and can only be removed by bending the plates back. The next stage is to form cells. A large number of plates are put together in a trough, the positives and negatives being kept apart, and each plate is separated from the next by a frame of india-rubber. The dilute sulphuric acid is then poured in, and the plates are slowly peroxidized. They gradually become blackened upon the lines of the lead-work, the centres of the holes being the last portions to change colour, and the whole surfaces are in a spongy condition, accessible to the liquid. A peroxidized plate has a soft crystalline appearance of a deep brown colour. The plates are then stored in Faure cells ready for use, being carefully isolated by the india-rubber bands. Another plan is now being tried by Thornton, of pushing out the composition from certain holes, and filling them up with projecting india-rubber plugs; but if the plugs are not bent, no contact is possible under the present plan. The state of saturation in the liquid is ascertained by an ingenious copper balance and hygrometer. The plates are made in 2 sizes, one double of the other, and are packed together, 9 positives and 9 negatives, in a box. The small sizes of cell are known as $\frac{1}{2}$ h.-p., and the large ones as 1 h.-p. cells, the term signifying, of course, such a power "per hour," and combinations

of cells are manufactured up to 5 h.-p., the only difference being in the number of plates per cell. About 16 ampères per hour can be stored in a small pair of plates, and such a pair will discharge a current for 6 to 8 hours, giving forth 160 ampères. Having explained the process of charging and discharging the cells, Dr. Lodge mentions that the reduction of the sulphate is rather troublesome, and it is desirable that no more sulphate should accumulate than is absolutely necessary. It grows more rapidly during idleness than in action. Indeed, if kept in action, these cells are very efficient; but if suffered to be idle, they rapidly degenerate. Much of the difference found in cells is due to their comparative use and idleness. The sulphate on the positive plate is less important than that on the negative, because the oxide attacks the former far more readily. The secret of the most economical use of a secondary battery lies in charging it slowly, never filling the cell beyond its capacity, and in never completely draining it; it should be discharged as slowly as practicable. The electromotive force in a small or $\frac{1}{2}$ h.-p. cell is about 2 to 2·1 volts per hour, or about 20 ampères for 6 or 8 hours. The amount of energy is nearly uniform for this period, and then rapidly falls—a far more satisfactory condition than one in which the cell regularly diminishes in power from the commencement.

Prof. Lodge points out the extreme value of peroxide of lead, it acting better than any other known electro-negative. In an experimental cell he used 2 plates of lead. If he substituted a clean piece of platinum for the negative lead plate, the platinum acted as plus to the peroxide of lead, though whether it was really attacked by the dilute sulphuric acid he could not tell. But by substituting for the platinum a piece of copper, the latter metal was more strongly plus, and its action, as tested by the ringing of an electric bell, was not only stronger, but of longer duration. The copper was dissolved, and formed a sulphate of copper. This would proceed either until the dilute acid was saturated, and could take up no more copper, or, if the copper plate was relatively small, until it was completely dissolved. This is the principle of a Sutton cell, but with the action reversed. As tested by its ability to ring a bell, such a cell shows for some time no signs of falling of. It is not very clear why the Sutton cell is not in more general use, although possibly it is liable to run down during the night or when idle. Lead is not strongly plus to peroxide, and hence the use of a lead plate as a support for the peroxide. Gladstone and Tribe have said that a thin coat of varnish formed on the plate. On removing the peroxidized or positive plate from the cell, and substituting for it a hydrogenized plate, a very slight, almost infinitesimal action, is perceptible. This film or scum on the lead is therefore resistance; and the result of the experiments is not due to electromotive force, and this scum is of very great value in preventing local action on the plus plate. Using a piece of spongy lead, the scum or film takes longer to form, and the electric bell will ring for a considerable period. Lead can be rendered spongy or porous in various ways—electrically, chemically, or mechanically; and by any of these means one can obtain an almost indefinite extension of the surface of the negative or minus plate, thus postponing the period at which the scum formed on its surface renders it effective, and enabling it to outlast the positive or plus plate. In passing, he refers to the great advantage derived from the inactivity of lead in its use as a support for the peroxide. When he took a piece of clean lead for the peroxide plate, it refused to pass a current after the first instant, and if this were not the case, they would be unable to use it as a support on account of the local action, for the plate and its peroxide coat would act as a miniature cell. Thus, if a piece of copper fell into a cell of this class, a primary battery would be formed, and holes would be eaten into the lead. The reason for this protection was the thin but insoluble film of sulphate of

lead which protected the plate, and was vital to the life of the cell, for if it were soluble, a violent effervescing action would be set up. Experiments have shown that manganese is not so good as lead. It has been attempted to meet some of the defects of lead by using carbon with it, but the coat is non-adherent and troublesome. Lead is therefore, on the whole, the most suitable material at present known. The minus plates can be improved by being made spongy, or perforating or folding them. The plan adopted by Watt, of Liverpool, is to force a jet of steam under high pressure against a stream of molten lead, which is thereby deflected against a board, from which it is removed in a spongy condition. In the Sellon-Volckmar cell, the lead is perforated, and in the process of Kabath the metal is bent or folded. The plates may again be coated with salt of lead, either electrically, as in the Planté cell; chemically, as in Schultzer's, who prepares his plate incrusted with a thick sulphate; or mechanically, as in Faure's process. In all the varieties of coated plates tried, Lodge had not found anything much better than the Planté cell; but several other considerations had to be borne in mind in selecting secondary batteries, such as internal resistance, weight, and compactness of the cells. The ½ h.-p. Sellon-Volckmar-Faure cell is equivalent to 20 ampères, 2 volts in 9 hours, and the h.-p. cell is just double that power, and equals the raising of nearly 2 million foot-lb. The percentage of quantity of available work is very good in these cells—from 80 to 90 per cent., and even more, of the charge being utilized; and it is well established that the more slowly a cell is charged the less waste is apparent, and were it practicable, the discharge should be equally slow. The next point is as to the use of the secondary battery; and the first, because most obvious, is for lighting purposes, for which the cells have many advantages. As stores for electric power for use in lighting conveyances making short journeys, they will be highly useful. Small vessels, cabs, and tricycles can carry with them boxes giving sufficient power for some hours' lighting; and it is well known that the Pullman train between London and Brighton has for some time been lighted by secondary batteries. Another advantage is that by this means you can use for a short time a higher power than an engine can give. It is not economical to run an engine for a few hours only, and by the cells the engine can be kept going all day, and a larger horse-power can be expended in lighting energy during the evening. There is less danger of sudden extinction, for a cell is not liable to give out suddenly, as is a belt to slip from an engine. Greater steadiness of light is attainable, the secondary battery acting as a governor, and it will also be utilized as a governor, performing the function of a cistern or so-called gasometer. Any fluctuation in the dynamo is not communicated to the lamps. If used for electric installations, the reservoir will probably be in a central place; but there are advantages in having separate boxes in each house. This is the cistern as opposed to the constant supply system, and it is probable that, as in water services, the latter, by which a central store supplies the force, will be most popular. The central supply of electromotive force will be equally available for incandescent, arc, and other forms of lamp at the same time. The excellence of the result is due to the remarkably low internal electrical resistance of the cells, and in this respect they differ from any batteries. In these cells the internal resistance is as small as ·0016 of an ohm, rising to ·002 of an ohm when nearly exhausted. Where a gas-engine is employed it is not important, as with a steam-engine, to keep it continuously at work, and with this motor the secondary battery should be used as a regulator rather than a store. A waterfall is an instance of a motor where economy demands that it shall be employed continuously; by the use of secondary batteries, a 70 h.-p. fall would provide a 100 h.-p. light at night. For domestic lighting, the problem is how

to reduce the electromotive force so as to render it perfectly safe for household purposes. Dynamos have a high internal resistance: secondary batteries will give the same amount of electromotive force with far less resistance. For an energy of 2000 h.-p., the resistance would, with the cells, be less than 2 ohms, but would rise to about 400 ohms with a dynamo. A high electromotive force is most economical; but to obtain this directly from a dynamo, the rate of revolution must be enormous, and the friction is correspondingly great.

On the formation and construction of lead batteries, some valuable notes have been contributed by J. T. Sprague to the *English Mechanic*, mainly as follows.

Planté's directions for charging are to effect 6 or 8 reversals of current the first day, prolonging the successive charges; this is continued next day till the duration of useful charging becomes a couple of hours; at this limit it becomes necessary to give intervals of rest between the charges, during which a local action takes place: these rests require gradual prolongation to several days, and even weeks; after the cell approaches the capacity of storage intended, the current should not be reversed, but the cell should simply be charged and discharged as if in actual work. The process of this forming, therefore, occupies some months, except with very thin plates, and if pushed too far, the whole substance of the plate may be converted into peroxide, which would render it liable to break up, and would increase its resistance.

Heat assists the formation and reduces the time required for the process; therefore during the process of charging the temperature may be advantageously raised to 100° to 160° F. (38° to 71° C.), and allowed to fall as soon as the charge is effected. But heat is objectionable in actual working, because it facilitates the oxygen and hydrogen assuming the gaseous state and going off to waste.

Alcohol added to the extent of 5 per cent. to the acid solution is said to assist the formation. Berliner states that it requires but an hour to develop a heavy oxide surface capable of taking a large charge.

Nitric acid is recommended by Planté, who says that by soaking the plates for some hours in nitric acid mixed with an equal volume of water, he has greatly reduced the time of formation. The effect is to produce a porous surface more quickly acted upon; but it is evident that for this treatment the plates should be thicker.

Electro-deposited lead has been tried for the same object. But lead is a very troublesome metal to deposit; unlike other metals, it does not spread as an even film, but will dart out in fine arrows from points on the surface, which either fall off as they lengthen, or close the circuit to the other plate; for this reason the presence of lead salts in solution, or the use of acids, &c., which will dissolve lead, is very objectionable.

Amalgamation of the lead has been employed by Paget Higgs. It is by no means clear that it is an advantage on the whole: it must tend to weaken the lead, and therefore to fracture of the plates. It is not desirable or useful at the peroxide plate, because it resists the formation of PbO_2, and tends to form oxide or salts of mercury; the mercury also prevents the molecular union of the lead and peroxide, which latter therefore tends to separate from the plate. It is probable that mercury facilitates the absorption of hydrogen at the leaden plate; but even there the advantage is very doubtful, because in regular working the real action which goes on is the reduction of the lead sulphate which has been formed during discharge.

The plates may be either flat plates interleaved like those of a condenser, or they may be large plates rolled up as cylinders, or folded up together. Flat plates give a simpler construction, and have the great advantage that they can be "formed" in a separate vessel and combined as desired; each can also be removed singly in case of injury, and easily replaced. They have a serious disadvantage, however. It is evident

that the molecular volume of lead salts exceeds that of lead, so that there is constant expansion and contraction going on, which tend to produce bulging surfaces, and this much more readily upon flat parallel plates. It is therefore desirable to introduce slips of glass or other insulating material to resist this, and prevent the plates coming in contact. The cylindrical form is made by laying a long sheet of lead on a table, placing upon it a number of strips of soft vulcanized rubber arranged diagonally upon the lead, then another sheet of lead with similar diagonal strips; the sheets are then rolled up firmly so as to form 2 parallel spirals separated from each other. The insulating strips can be inserted as the rolling up proceeds. The thickness of the lead must be sufficient to bear its own weight and the strains put upon it after use; the peroxide plate should therefore be about double as thick as the other. In large batteries, lead 1 millimetre (·03937 in.) thick is used, or about 24 sheets to the inch; 1 sq. ft. of lead 1 in. thick weighs 59·1 lb., therefore this would be about $2\frac{1}{4}$ lb. lead. The smaller cells are made of lead little thicker than that prepared for damp walls, which is about 4 to 5 oz. per ft. For ordinary purposes, it is probable that sheets of $1\frac{1}{2}$ lb. and 1 lb. would be most advantageous, with the formation carried so far as to convert $\frac{1}{2}$ lb. of the lead to peroxide on the one plate.

Connections must be provided to the sheets in either form, and the best is made by strips of lead attached carefully to the sheets by soldering, which should be well protected by good cement; copper wire should not be used, as it is sure to be acted upon, and form salts, which will exert a very mischievous action.

Containing vessels may be of any suitable material, but glass has the great advantage of permitting the action to be watched; if leaden, or wood lined with cement, or other opaque vessels are used, they should be covered with sheet glass for this reason. They must not be entirely closed, because gases are generated, and must be allowed to escape; they should not be uncovered, in order to resist evaporation, and also for prevention of dirt, which would be likely to result in short-circuiting the plates—a thing very likely to occur, and obviously injurious to the working.

Space for acid must be allowed, sufficient to effect the action; therefore the distance of the plates must be so adjusted. Circulation cannot be depended on, but it is desirable to raise the bottom of the plates above that of the vessel, and to allow the liquid to rise above them, in order that the heat and escape of gas may tend to produce a current, and to draw the external acid between the plates; 1 lb. of lead requires $\frac{1}{2}$ lb. of acid to convert it into sulphate, and as by th foregoing proportions there would be $\frac{1}{2}$ lb. of lead to be converted on the 2 faces of lead opposing per sq. ft., this requires space for $\frac{1}{4}$ lb. of acid, which, diluted as 1 to 10, would be contained in a space of $\frac{1}{3}$ in. between the plates.

The strength of the acid varies during the action, becoming strongest when the charge is complete, and one plate is converted into spongy lead and the other into peroxide; when discharge is completed, a great part of the acid is absorbed in the formation of sulphate of lead. Several consequences result: (1) the resistance of the battery is lowest just when its electromotive force is highest, and *vice versâ*, which introduces a variation in the current generated at different periods of discharge; (2) when the material consists of a porous mass containing liquid confined among its interstices, the acid may be entirely removed at an early period of the discharge, and consequently much material remains unacted upon; also, the residuary liquid being highly resistant at the next act of charge, the current cannot reach the material. As a consequence, a cell containing a large mass of active material may be able to do but little work. This defect is also an accumulative one: portions of the mass become practically non-conducting, and insulate other por-

tions to which the acid has access, because in very dilute acid, instead of the normal sulphate $PbSO_4$, there is a tendency to produce the basic sulphate $PbSO_4 + PbO$, which is not readily reduced by hydrogen.

To charge a secondary battery it is necessary to employ an E.M.F. greater than its own, and greater in proportion to the rate of charge desired. All such excess of E.M.F. is energy lost in overcoming resistance; therefore slow charge is most economical under this head, though other practical considerations have to be taken into account, *i.e.* against energy lost at the rate of the square of the current generated, must be reckoned time and interest on plant. But in addition to the loss of energy involved, a small charging current is desirable for 2 good reasons: (1) the product is in better condition, the particles being in closer contact and better electrical connection; (2) there is less loss by uncombined gases escaping.

Throughout the charging there is a constant escape of gases going on, chiefly oxygen; and the loss of either gas means total loss of the equivalent of electricity involved in the decomposition from which it arises. If O is wasted, H is lost too, or the total power of the cell is reduced by its incapacity to take up the O. But the escape of H indicates either that the rate of charging current is too great, or that the limit of the economical charge is approached. The rate at which a unit area of surface can act properly, in the case of a secondary receiving charge, is a lowering capacity, because it is related to the diminishing quantity of lead sulphate remaining unconverted. The increase of free acid tends to increase the current, and the combination of these 2 causes results in a growing loss of gases as the charge proceeds. Obviously, therefore, it is bad economy to press the charge to the full capacity.

The electromotive force is about 2·25 volts immediately after charging, but falls spontaneously to 2 volts. This high initial force cannot be due to the free H and O, because their force of combination is only 1·5, but it is easily accounted for by the presence of ozone, which is oxygen charged with a higher energy in order to force the third atom of O into the molecule. The normal E.M.F. of 2 volts is subject in working to a fall such as occurs in ordinary batteries to an extent increasing with the rate of current, and due probably to the change in the liquid particles adjoining the plates: therefore the E.M.F. rises again after a short rest has allowed fresh liquid surfaces to reach the plates by diffusion. The average rate of working E.M.F. is probably 1·9 to 2 volts.

Metallic solutions, while promising in appearance, do not answer in practice. The action, unless very slow, alters the layer of liquid in contact with the metal, which then refuses to act; in charging, after the first action, there is no metallic salt present to decompose, but only acid which gives off gas, and so the metallic deposit becomes non-coherent; in discharge, the metallic salt forms too rapidly to dissolve, and crystallizes on the plate.

Acid solutions other than sulphuric might be used, and no doubt will; but hydrochloric acid when electrolysed does not give up H and Cl simply—it is always accompanied with oxygen, and the result is the formation, not of chlorides, but of oxychlorides, which are exceedingly refractory in reduction; for this reason, the silver chloride battery fails in reversal, or it would constitute an admirable storage battery.

Alkaline solutions cannot be used with lead, because they dissolve it; but they may be employed with some other metals, as iron, which would absorb H at one plate and form peroxide at the other, producing a battery of rather low E.M.F.

In charging a number of cells, it is necessary so to arrange them in series and in arc as to distribute them on the same principles as ordinary battery cells when a number are used together. So many must be ranged in series that the number multiplied by the E.M.F. is so

much below the charging E.M.F. as allows the required rate of current to pass; that is to say, E (or $2{\cdot}25)\times n\times 1{\cdot}25$ = E.M.F. of source, assuming that this is to exceed the counterforce of the battery by $\frac{1}{4}$. So many must be ranged in multiple arc as brings the united resistance to such a ratio to the available E.M.F. as will permit the intended rate of current to pass; such rate being well below the proper working density suited to the area of the plates.

It is of the utmost importance that all cells to be worked together shall be fairly equal, for, as in a chain, the capacity of a combination is that of the weakest link; if some cells become inactive in discharge, they are not merely useless, they begin to take charge in the opposite direction and oppose their E.M.F. If several sets in multiple are differ in E.M.F., which will occur if their conditions differ, some of the sets will not get charged, or if left so connected when the source is not acting, they will be reversed, and the charge be wasted.

The charge should not be carried to more than $\frac{3}{4}$ of the capacity. The discharge should not be carried farther than $\frac{3}{4}$ of the charge actually stored; and the battery should not be charged, if avoidable, long before it is intended to be used.

Each cell should be occasionally tested as to its condition, in order to discover any derangement or accidental short circuit, and any cell showing unusual evolution of gas should receive immediate attention.

Galvanometers should always be kept in circuit, to give warning as to what is going on; and automatic cut-outs are very useful in case of a failure of the source, or other accident. Such appliances are easily made with an electromagnet inserted in the circuit, or in a shunt circuit, with a permanent steel magnet for the armature, mounted on a spring, and completing the circuit only when held down: the attraction of the armature for the core will hold it down ordinarily; but if a reverse current arises, the armature leaves the magnet, breaks the circuit, and can be made to ring a bell to call attention.

It is asserted by some that secondary batteries will return 90 per cent. of the energy stored. It is quite likely that 90 per cent. of the electricity, reckoned in coulombs, might be obtained, provided the battery were used not long after charge. But what is really important is, the energy depends upon the E.M.F. as well as the current; and as the E.M.F. of charge must exceed that of discharge, and may probably exceed it by $\frac{1}{3}$, here is an inevitable loss, which cannot be defined for all cases, because it will depend upon the ratio of the external and internal resistances. This only gives the loss upon actual storage; there is to be added that lost in the act of charge, and that carried away in the escaping gases. When all these are considered, it is almost certain that, on the average, the use of storage batteries means the loss of 50 per cent. of the energy as compared with direct working. This means doubling the cost, irrespective of the value and expense of the battery itself. (J. T. Sprague, *Eng. Mech.*)

Henry Greer, of New York, gives a good detailed account of the construction of the various secondary batteries before the public, in his pamphlet on the 'Storage of Electricity.'

Telephones. — Before describing the construction of various forms of telephone, it is necessary to explain the principles underlying its mode of action. The sensation felt in the organ of hearing, and known as a "sound," is due to waves or vibrations in the air acting upon the tympanum of the ear. In this transmission of sound, the particles of air or other conductor are not transported, but the vibration of one particle is communicated to the next, and so on, the intensity becoming less as the distance increases. This constitutes the main fault of the so-called "string telephone," the earliest and simplest form of apparatus for communicating speech —its range is limited. The telephone proper differs from other instruments of a like class, in that it reproduces

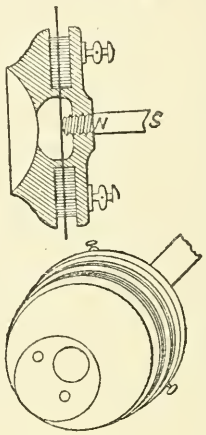
instead of merely conveying vibrations, and has thus a practically unlimited range.

Forms.—Various forms of telephonic apparatus may now be discussed.

(1) String Telephone.—This is formed of 2 metallic or cardboard tubes, in the shape of a cylindrical cone; one end is closed by a tightly-stretched parchment membrane, in whose centre the string intended to connect the 2 cylinders is fastened by a knot. When 2 such tubes are thus united, and the cord is tightly stretched, words may be conveyed along it by the speaker placing the opening of one tube to his mouth, and the listener putting his in the same way to his ear. The distance which may thus be traversed does not exceed 170 yd. The best results are said to be got from silken cord and the worst from hempen; cords of plaited cotton are generally used for economy. Some preference is given to nickel silver as the material for the mouth-pieces. Several modifications have been proposed. Millar ascertained that by means of a telegraphic wire, stretched and connected by 2 copper wires with 2 vibrating disks, musical sounds might be conveyed to a distance exceeding 160 yd., and that by stretching these wires through a house, and connecting them with mouth-and-ear holes in different rooms, communication between them became perfectly easy. For the vibrating disks he employed wood, metal, or gutta-percha, in the form of a drum, with wires fixed in the centre. The sound seems to become more intense in proportion to the thickness of the wire. Heaviside and Nixon ascertained that the most effective wire was No. 4 B.W.G. They employed wooden disks $\frac{1}{8}$ in. thick, and these may be placed in any part of the length of the wire. When the wire was well stretched and motionless, it was possible to hear what was said at a distance of 230 yd., and it seems that Huntley, by using very thin iron diaphragms, and by insulating the line wire on glass supports, was able to transmit speech for 2450 ft., in spite of the zigzags made by the line on its supports.

(2) Kennedy's Telephone (Figs. 106, 107) is of the "Bell" type, but differs in its principle of action and in construction. No coils of wire are used on the magnets; but 2 coils are used, one on each side of the ferrotype plate, the wooden case being turned out so as to form 2 spaces for the wire, also to grip the plate, leaving 2 in. of the centre of the plate for vibrating; the plate is 4 in. to 6 in. diameter; 2 to 4 oz. of No. 30 wire may be used in each space. The action of the telephone is this:—On current passing through the coils, the plate is magnetized, with its centre a S. pole, say; the plate is therefore drawn inwards. On a reverse current passing, the centre of the plate is magnetized as a N. pole; the centre of the plate is therefore repelled outwards — that is the action when it is used as a receiver of alternately reversed currents, such as produced in the Bell telephone or in the carbon telephone used with an induction coil as a transmitter. It may be used as receiver or transmitter just the same as Bell's telephone. A pair of them tried on the same circuit with a pair of Bell's, spoke much louder, and, what is of more importance, the articulation was much more distinct.

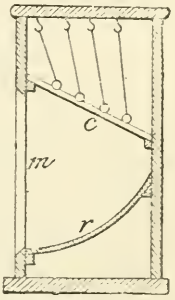
FIGS. 106, 107.



(3) Thompson's.—Prof. S. P. Thompson's improvements relate to telephonic transmitters based upon the principle discovered by Reis, of employing current-regulators actuated, directly or indirectly, by the sound-waves produced by the voice. By "current-regulator" is meant a device similar to that employed by

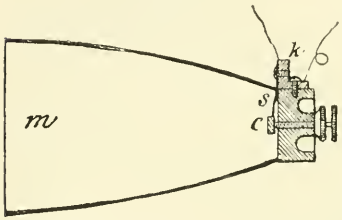
Reis, wherein a loose contact between 2 parts of a circuit (in which are included a battery and a telephonic receiver) offers greater or less resistance to the flow of the electric current, the degree of intimacy of contact between the conducting pieces being altered by the vibrations of the voice. In Reis's transmitter, in Edison's, and in other well-known forms of this instrument, the action is indirect, a tympanum of stretched membrane or other equivalent organ, such as a diaphragm of mica, being used to collect, magnify, or concentrate the vibrations of the voice, and to convey them to the points of loose contact that regulate the current. In other forms of transmitter (for example, some of Hughes's microphones), the mode of action is direct, the air-waves beating directly upon the conductors or electrodes which are in loose contact, without the intermediation of a tympanum or diaphragm. Of these 2 classes of telephone transmitters—viz. those in which the current-regulator is combined with a tympanum or diaphragm, and those in which the current-regulator is acted upon directly by the air-waves of the voice—the improvements relate to the latter only, as Prof. Thompson dispenses with the membrane tympanum used by Reis, the tympanic diaphragm of mica used by Edison, and does not even employ any diaphragm in the sense of a partition between the current-regulator and the air-waves of the voice, as in Theiler's transmitter. In Thompson's transmitters the air-waves act directly upon the current-regulator itself. As a result, the articulation is clearer for some of the consonantal sounds, which are only imperfectly or difficultly transmitted by telephones in which the current-regulator is affected indirectly through a tympanum, diaphragm, or partition. Transmitters of the class to which the improvements relate are ordinarily liable to 2 defects. Firstly, they do not articulate so loudly as transmitters in which there is a tympanum or diaphragm to collect or magnify the vibrations. Secondly, when, to obviate this difficulty, the speaker speaks with his mouth very close to the current-regulator, the moisture of his breath condenses upon the contact points or adjacent parts of the regulator, interfering with its action and spoiling the articulation. The improvements relate chiefly to means for remedying or obviating these defects. Prof. Thompson proposes to employ mirrors, sound-reflectors or reverberators (one form of which is shown in Fig. 108 in transverse section), consisting of glass, metal, wood, or other material, by which the sound-waves are turned aside from their direct path, and are made to converge upon the current-regulator, precisely as rays of light may be turned by a mirror. If actual mirrors of polished metal or silvered glass are employed for this purpose, they have the additional advantage of revealing to the speaker the presence of moisture. But in any case the mirror serves to collect the sound-waves as they come from the speaker's mouth, and to direct them on to the current-regulator while intercepting moisture from the speaker's breath: *m* is the mouthpiece or tube; *c*, the current-regulator; *r*, the reverberator. An adjusting screw and an outlet cock for the water which collects in the mouth-tube are also provided where necessary. The mouthpieces hitherto used on ordinary transmitters are not intended to serve either as reverberators or as protectors from moisture, and Prof. Thompson finds that mouth-pieces for this purpose must, as shown in Fig. 109, be deep and of conical or paraboloidal form. Another part of the invention consists in employing for the current-regulator such materials as are at once neither hygroscopic, nor liable, by their properties with respect to heat, to condense films of moisture, while at the

FIG. 108.



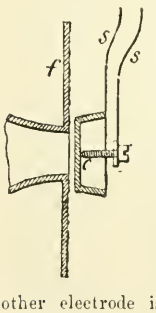
same time they are good conductors of electricity. Prof. Thompson prefers to use as materials for the current regulator, either spongy platinum, carbide of platinum, boron, coke, carbon, or

FIG. 109.



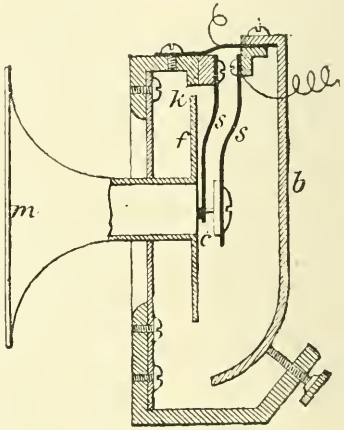
elastic carbon specially prepared, having first deprived such materials of their hygroscopic properties by treatment with petroleum, or other suitable hydrocarbon. In some cases, and especially where the contact surfaces of the current-regulator are of metal, he finds it convenient to keep their surfaces constantly moistened with petroleum or other hydrocarbon by supplying them through a cotton filament in communication with a small lubricator. The improvements also consist in so arranging the parts of the current-regulator that the points of loose contact can be actuated by the sound-waves, whilst they are protected from the moisture of the breath by some portion of the conductors or electrodes projecting between the contact points and the breath of the speaker. An example of such an arrangement is given in Fig. 110, wherein the contact-points *c* are protected from the breath by making one of the electrodes in the form of a cup, against the concave face of which the contact-point on the other electrode is directed. The improvements relate further to the form

FIG. 110.



of the conductors or electrodes combined to serve as the current-regulator. The current-regulator of Reis, consisting of one piece of platinum resting lightly against another, is imperfect, except when, as in some forms of Reis's instrument, one or both the pieces of metal are fixed upon springs or some equivalent elastic support; otherwise, the current is liable to very abrupt interruptions. In Fig. 111 is shown a current-regulator,

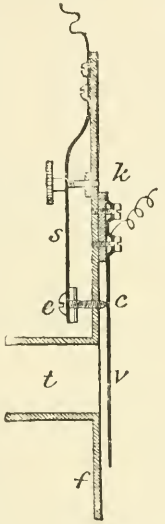
FIG. 111.



wherein the two contact pieces are held upon springs *s*; one of these springs is fixed to an adjusting frame *b*, and the other to an insulating block *k*, for it is found that when there are many points of contact instead of but a single pair of such points, there is less liability to such abruptness. Multiple contacts, therefore, are advantageous. One of the improved forms of current regulator consists of a framework of prepared carbon or metallic tongues, so connected that the current cannot pass from one to the next except through pieces of good conducting carbon or metal, suspended or resting in loose contact against the tongues. In the instrument shown in Fig. 108, the current-regulator *c* consists of an inclined grating of carbon strips, against which the voice-waves

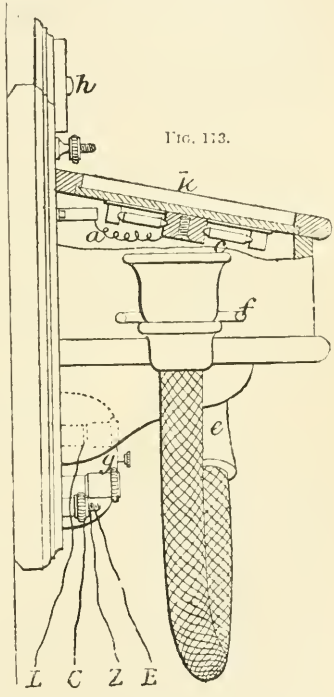
are reflected by the reverberator *r*, and upon which rest light balls of carbon or metal suspended from hooks by silken strings. In some cases, where a highly powerful action is desired, the air-waves are caused to act first on a vibrating tongue, which then transfers the vibrations indirectly to the current-regulator or contact points *c*. Such a vibrating tongue is shown at *v* in Fig. 112, where it is attached behind a flanged tube *t*, the contact-points or current-regulator *c* being on the same face of the tongue *v* as that against which the voice-waves impinge. This tongue may be itself an electrode, and serve as part of the current-regulator, in which case it is formed of metal, carbon, or elastic conductor, whether anhygroscopic or not. (*Eng. Mech.*)

Fig. 112.



(4) Gower's Telephone is a combination of a telephone and microphone in the same case, which arrangement affords all the advantages obtained by the employment of a battery for communication, without its accompanying objections, and without destroying the effect of the telephone when it is employed as a transmitter in the case of a battery failing. Fig. 113 is a side elevation of the apparatus partly in section, a portion of the side of the box being removed in order to show the communication between the microphone and the principal circuit. Fig. 114 is a plan, the microphone being removed in order to show clearly the arrangement of all the parts on the interior of the box. Fig. 115 is a plan of the underside of the microphone shown in Fig. 113. This microphone is connected with the principal circuit by means of wires, which are broken off in the figures.

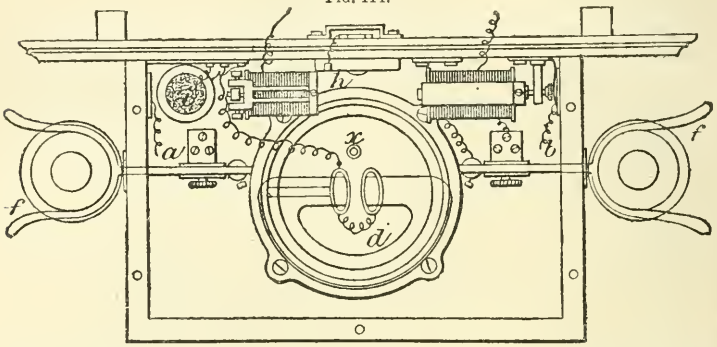
Fig. 113.



When the plate of the microphone is in the position shown in Fig. 113, so as to close the box, the wire *a*, Fig. 115, is joined to the wire *a*, Fig. 114, and the wire *b*, Fig. 115, is joined to the wire *b*, Fig. 114. In constructing the apparatus, a microphone *c* of any suitable construction (but by preference having at least 6 contact-points) is attached to the upper part *k* of a box, the lower part of which box is provided with a Gower telephone *d*, constructed in the form known as the chronometer telephone. This telephone is provided with a bifurcated acoustic or speaking tube *e*, having 2 branches, in order to enable the ope-

rator to listen with both ears if required. Commutators *f* are provided at the side of the box, for the purpose of interrupting the passage of the current from the battery, and opening the circuit of the call-bells. After working the apparatus, the extremities of the acoustic tubes *e* are placed in holders connected with the commutators *f*, and the circuit is thereby interrupted. An electric call-bell *g* is provided underneath the box, and a knob *h* for working the call-bells is placed at the upper part of the apparatus. An induction-coil *i* is situated inside the box, and the microphone *c* and the battery are connected to the primary circuit, whilst the Gower telephone and the line are connected with the secondary circuit. In speaking against the upper part *k* of the box,

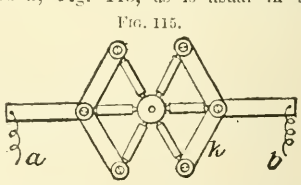
FIG. 114.



which may be of wood, iron, brass, or other suitable material, and near or upon the under surface of which the microphone is placed either with or without attaching the microphone to the box top directly, the sound-waves from the voice form electrical undulations in the primary circuit through the action of the microphone, and these undulations are reproduced in the secondary circuit by induction, and are thus repeated in the Gower telephone at the receiving station. Especial attention is directed to the fact that the microphone in this combination is not necessarily attached to the box top, but that it may be carried upon a framework attached at any point to the combined apparatus. The undulations, however, when so reproduced, are intensified to such an extent by the great power of the magnet in the Gower telephone, that they act upon the microphone in the same case with such effect as to set up corresponding undulations in the primary circuit at the receiving station, and these undulations are again reproduced in the Gower telephone with increased intensity.

Moreover, when the diaphragm of the telephone is provided with a vibrating reed *x*, Fig. 115, as is usual in the

FIG. 115.



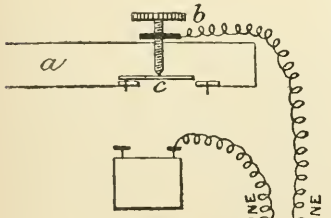
Gower telephone, it is simply necessary to close one of the branches of the acoustic tube, and blow into the other branch, in order to cause the reed to vibrate, and thus produce powerful vibrations of the plate before the magnet. These vibrations not only produce currents in the coils or the poles of the magnet, but also act with great power upon the microphone, the sound being produced in the interior of

the same box, and thus double the effect of the signal current on the line wire without exhausting the battery to any greater extent than when speaking in the usual manner through the apparatus.

By employing this combination of magneto-electric and electro-magnetic currents, it is possible to act with great power upon what is known as the "Ader" disc, or upon any other suitable receiving instrument at the distant station, as well as in the case of a system worked with a central office, and any suitable arrangement of the mechanical parts may thus be employed at the receiving station. It also results from the employment of this combination that a failure of the battery will not stop the communication, the Gower telephone being always capable of working the apparatus, whether employed as a receiver or as a transmitter, provided that the wire is not broken, whilst it is also possible, when the Ader signalling apparatus is employed at the central office or other receiving station, to transmit a signal without employing a battery, as in the case of the ordinary Gower telephone. The employment of bifurcated or double acoustic tubes obviates the necessity for having a separate instrument as receiver, and thus enables the flexible conducting wire to be dispensed with, which wire constitutes one of the principal objections to the use of telephones in practice.

(5) Calls.—(*a*) This is not so noisy

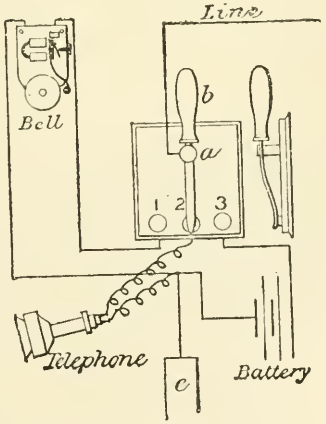
FIG. 116.



as bells, yet sufficient for the purpose. Fig. 116: *a*, tube; *b*, brass screw, platinum-pointed; *c*, brass block and platinum reed. On blowing into the mouth of the tube at *a*, a musical note is produced by the vibration of the reed *c*, and the circuit is interrupted at the point *c*, the effect of which is that the note is produced at the distant station with nearly the same force. The effect would be augmented if a small induction-coil were placed with its primary terminals, connected across at zinc line, and the ends of secondary coil joined to zinc proper. The point of the screw may be nearer the end of the reed than is shown

(*b*) Fig. 117: *a*, board; *b*, brass spring fitted with a handle for convenience of

FIG. 117

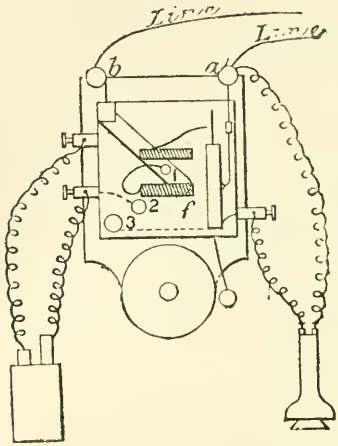


shifting; 1, 2, and 3 are the studs, connected as shown. It will be observed that one of the wires from telephone bell and battery is connected to the earth-plate *c*, or return wire. In the position shown, the telephone is in use; if the spring is moved to No. 3, the bell at the other end of the line (the apparatus is supposed to be in duplicate) will ring, provided the switch is on No. 1 stud. Keep the switch on No. 1 to let the home bell be rung. (Cory.)

(*c*) Fig. 118, making the bell-case act as switch-board. *a b* are the line ter-

minals; *a* is in connection with one terminal of bell, battery, and telephone respectively; *b* is connected with switch-

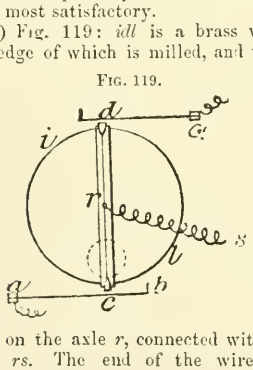
FIG. 118.



arm *f*, moving over studs 1, 2, 3, which are the other terminals of bell, battery, and telephone. Dotted lines on the box show the connections inside, which can be easily made out if each circuit be followed separately. The action has been most satisfactory.

(*d*) Fig. 119: *idl* is a brass wheel, the edge of which is milled, and which

FIG. 119.

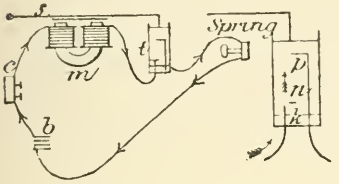


runs on the axle *r*, connected with the wire *rs*. The end of the wire *s* is connected with one of the poles of an electric battery, the other pole of which is connected with the earth-plate or return wire; *cd* and *ab* are springs, *a* being connected with the earth-plate through the telephone, and *c* with the line wire; *crd* is a flat piece of ebonite (or wood steeped in paraffin), with two brass studs *d c* fixed into each end, and in metallic connection with one another by a wire; this ebonite is firmly fixed on the wheel, so as to insulate the studs *d c* from it. The dotted circle at the bottom of the wheel represents a lump of lead, fixed behind, so as to keep the wheel in the above position when not being turned by a handle fastened in front. It will be seen that when the wheel is turned out of the above position, the spring *cd* will press upon the milled edge of the wheel, and thus establish electrical communication between the wire *c* and the wire *s*, which is connected with a battery. But when the stud at *d* is moved round, the stud at *c* will also move, and the spring *ab* will then be released, and tend to press on the edge of the wheel, from doing which it is restrained by a small pin in front of the spring at *b*. In the position shown in the figure, a current entering at *c* from the line wire would take the course *cdca*, and then go back through the telephone and earth. When the wheel is turned, however, any connection between the spring *ab* and the wheel is impossible, on account of the pin at *b*, but the spring *cd* presses on the milled edge of the wheel, which is connected with the battery, and thus, while the wheel is being turned, numerous small currents are sent along the line, which generate a loud musical note in the telephone at the other end, and thus call attention. No bells are used, and when attention is to be called at the other end of the line, a handle has merely to be turned; the trouble is thus extremely slight. (T. A. Garrett.)

(6) Augmenting Sound (Fig. 120).—A simple contrivance for augmenting the sound of the telephone, by increasing the variations of current by pressure on a tube filled with powdered carbon, caused by an electro-magnet. The current from the battery *b* flows through carbon telephone *c*, where it meets with varying resistance; from this it goes to

the electro-magnet *m*, which it magnetizes and causes to attract a small piece of soft iron attached to the spring

FIG. 120.

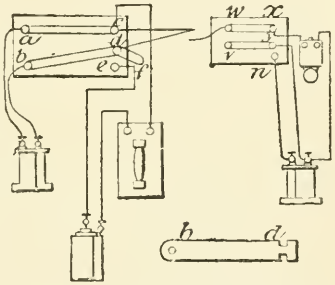


s, and produces pressure in the glass tube *t*, which is filled with powdered carbon. From the magnet the current passes to a wire introduced into the lower part of *t*, the bottom of which is stopped with a cork; from this wire it passes through the powdered carbon to another wire higher up in the tube. When the current is strongest, there will be the greatest pressure on the carbon, and so the least resistance; when it is weakest, there will be least resistance. The tube by itself is shown on the right. The bottom is stopped by a piece of cork *k*, through which are introduced the wires *p* and *n*, of which *p* is covered with an insulating substance as far as the bent part. In the top of the tube is fitted a piece of thin iron, against which the spring is caused to press.

(7) Cheap Magnets.—Procure from a saw-sharpener 2 old 6-in. 3-square files, worth not more than 1*d*. each. Put one in a vice and knock the shank end off (that which fits in the handle) to within ¾ in. of main part of file; take out, measure off 5 in. from shank, put the file in the vice the reverse of what it was, and knock the other end off, as near as you can so that it will be 5 in. in total length, and you will have (when magnetized) a magnet with an iron pole-piece, the shank being much softer than any other part of the file. Grind the shank round as near as you can, for your coils to go on; with such magnets you can lift a ¼-lb. iron weight. They also work through greater resistances than the roll steel commonly used. They speak very plainly. Magnetize them with 3 horse-shoe magnets, putting 2 on the table with their opposite poles 4 in. apart. Bridge the spaces with 2 files, and use the third for magnetizing. Commencing at the centre of the file, rub it to one end of the file, then return to the centre and pass to the other end, and so on, finishing at the centre, and slide the magnet off; then proceed with the other one.

(8) Circuits.—(*a*) Switches for telephone, microphone, and bell (Fig. 121).

FIG. 121.

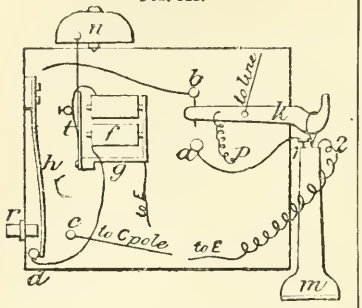


To ring bell, move the brass slip *ac*, working on *a*, to form *ad*; and upon moving *bd*, working on *b*, to form *bc*, the bell will ring if your battery is strong enough; if not, place a piece of copper wire to join your telephone terminals, which will take out the *r* of the coil within, as shown. The receiver hearing the bell, turns *vy*, working on *v*, to form *vz*, and then *wx*, working on *w*, to form *wy*, and answers. The transmitter now may speak by the microphone, or by replacing strips as shown by telephone alone. *df* is to cut out the telephone and use microphone alone. The message ended, all strips are replaced as shown; the battery circuit is then broken until you require to "telephone" again, proceeding as before. Telephone wire is usually small; consequently, the resistance through it, the telephone coil, and coil bell, is considerable. (Hannen.)

(*b*) Telephone Circuits and Call (Fig. 122).—When the button *r* is pressed, the spring *h* makes contact with support *c*.

A current then flows from battery to *c* through spring *h* by means of a wire to *b*, thence through *k* to the line. Through

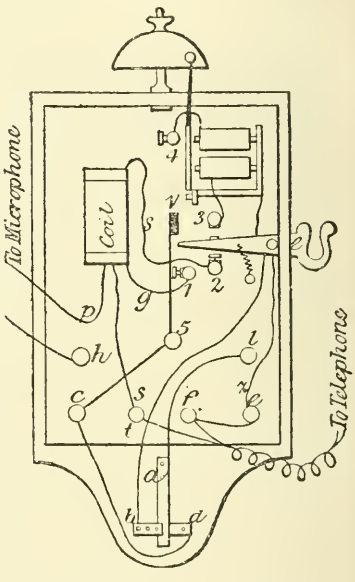
FIG. 122.



the line it enters the other end through *kbh* to *d*; from *d* through coil *f* to terminal *t*, through the keep and frame *g* to earth, ringing the bell *n* as it does so. On taking the telephones off the hooks at both ends, the currents produced by speaking into them are sent through *a* to *k*, and then to line entering *k* at the other end through *a* to the telephone there, and from end 2 of bobbin to earth or return wire. These connections can be made out of any old pieces of brass, screws, &c., and fitted up in a box. So long as the contacts are clean and firm, it will work as well as if better made. *k*, automatic switch arrangement, brass hook pivoted so that a spring fastened to it and point *p* would keep it down firm on *a* if telephone *m* were taken off; *a* is connected with one end of telephone bobbin; *b*, brass post so placed that *k* presses firmly against it when *m* is on the hook; *h*, brass spring normally pressing firmly upon *d*, and capable of being pushed hard against *c* by means of ebony button *r*—it is connected by a wire to *b*; *c*, brass post connected with positive pole of battery; *d*, brass post connected to one end of coil of bell movement *f*; 2, an end of telephone bobbin connected to earth or return wire.

(*c*) Ditto (Fig. 123).—This is the same as supplied with the Blake's Transmitter, and is as simple as any. The hook *c* has the telephone off; the spring *f* has drawn the hook contact down on contact 2; *s* is the secondary wire of the coil; a current coming from *s* passes through contact 2 into hook to *b*, through contact to *a* to terminal *l*, this being line. The other end of secondary *s* is fixed to terminal *t*; *f* is connected to terminal *ze*; zinc of battery and earth is connected to terminal *ze*—hence

FIG. 123.

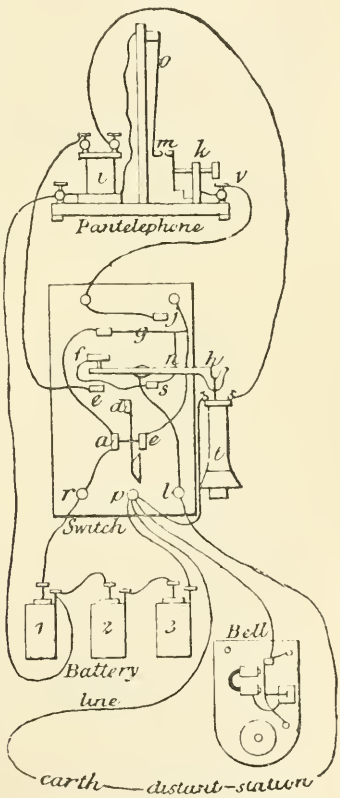


the two letters; the telephone cord is connected to *tf*; the primary wire of coil, one end *p* to microphone, the other end *g* to contact 1; *h* is terminal of transmitter zinc; *c* is terminal for copper or carbon end of battery. When the telephone is on the hook, it draws it down and places hook contact in contact with bell contact 3. A current now being sent from the other end to ring up, passes through *lab* to 3 through bell coils, regulating screw 4, through keeper and frame to *ze*. The act of taking off the telephone allows the hook to slide

off the vulcanite *v*, and lets the ring 5 come in contact with contact 1; this puts *c* in connection with one end of primary *p*; the other end *g* was already in connection with *h* through the microphone. The instrument is now ready for speaking to. A current coming through line passes through *ab*, hook 2, secondary wire to *t*, through telephone cords, coil, *f* to *ze*. To ring up, *a* is pressed on *d*; this does not affect your own instrument, as *a* leaves *b* before it touches *d*, so cut your own instrument out. (Tolman.)

(*d*) Transmitter and Switch (Fig. 124). —The pantelephone is a good transmitter when combined with an induction-coil, not without. The hanging plate may be made of pastcboard, also of thin wood, with like results, but the best effects are got when the contacts are of carbon only. The figure shows a very useful switch suitable for working the 4 instruments required in successful telephony—viz., the telephone, microphone, bell, and battery. To call attention at the distant station, where it is assumed the same kind of instruments are in use, press the button *b* on switch for a second or two; this breaks contact with *c*, and makes contact with *a*. The current now flows from the battery, cell No. 1, through *a* to *d*, on to *f*, then along lever *h* to its centre, and down to post *l*, thence to line, and on to distant station, where it rings a bell; then to earth, and back again to central post *p* on switch, then to cell No. 3, and so completes the circuit. The "call" will be answered by the home bell ringing, produced by the same operation of pressing the button *b* at the distant station. This sends a current into the line to the home station, which, entering the switch at *l*, passes upwards to the lever *h*, along this to *f*, then to *d* and *c*, and upwards to one of the top parts, then out to bell, which it rings in passing, and on to centre post *p*, and back through earth to distant station, and so again the round is completed. Now remove telephone *t* from the hook *h*; the spring *s* at once lifts up this lever, and through the insulated connection (a silk thread) *n* allows the spring *g* to make contact with *j*. Contact is also at the same time made by the lever with *e*, and broken at *f*. This operation brings the microphone or pantelephone into action.

FIG. 124.

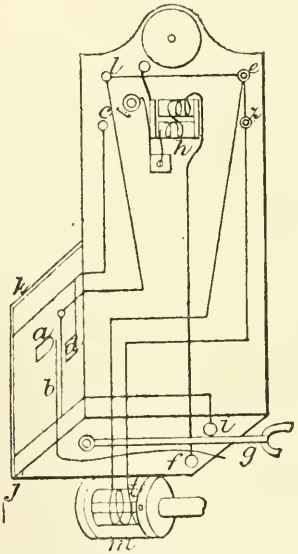


The current now flows from No. 1 cell only, this being sufficient to work the local circuit through the microphone. Its course is through *agj* to pantelephone, then passing by *k* through the loose carbons *m* to *o*; up this it passes by a wire, then down on the other side to the induction-coil *i*, where it flows

through the primary wire and back to the same cell No. 1. The secondary wire terminates in 2 binding posts on the top of the coil. This wire furnishes the current necessary to work the telephones. It starts, say, from the left-hand post and passes to *c* on switch, then along lever *h*, now in contact with *e*, and down to post *l*, thence through line to distant station, and through its telephone to earth, then back again it hastens to centre post *p* on home switch, and on through telephone to induction-coil, whence it started. The microphone bell and switch are best combined in one instrument. (Frank.)

(*e*) Switch for simplex Telephone (Fig. 125).—It is manipulated as follows:—

FIG. 125.

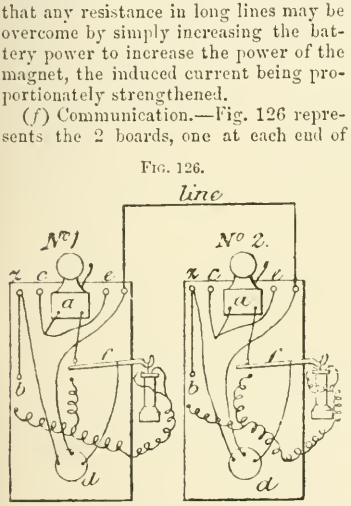


To call the distant station, press the button *a*, which breaks contact at *b*, and puts the line *l* and carbon of battery *c* in contact at *d*. The circuit is completed by putting the zinc of battery to *z*, whence the current passes through the receiver *m*, and out at *c*—either to earth or return wire. By this arrangement, the ringing at the distant station is repeated or made known at the sending station. The contacts at *b* are made with two strips of hard rolled metal, and continued under the lever *g*, which must be kept down on *f* while signalling with the bells, but be in contact with *i* when speaking. This is done by hanging the ear-tube on the lever hook, or the Bell receiver, should that be used instead of the electro-magnetic one. In coupling the instrument, the *l* of one is connected with the *c* of the other. The transmitter swings on 2 small brackets inside the front, and contact is made at *j* and *k* when the front is closed. The carbon-cups are made out of ½-in. carbon, and are best done with a rose countersink, large enough to take half the ball without touching the head of the screw which secures the cup in its place, or the cup may be glued in its place, contact being made by twisting a wire round the outside; the discs are made from slices of carbon-pencil with a groove round them to have wire twisted, and when the balls are screwed up in the case they should be quite free to rattle. The cups should be arranged 1 in. apart. An old saw and a file will do all the cutting and shaping, and if you have no lathe, a brace will answer the purpose. In the receiver, a bundle of iron wires takes the place of the permanent magnet, which was devised to meet the case of "Bell's" disclaimer, in which he disclaims a magnet excited by a battery in the line circuit. The adjustment of the diaphragm has to be made before finally screwing up, and will give no trouble if you observe to file the faces of the body of receiver and the core a dead level. Then cut a ring of stout writing-paper, with the hole about 2 in.; glue one on each side, and when the ferrotype plates are laid on, they will be the right distance from magnet, and may be screwed up. Instruments switched in this manner are as loud as any made; but they can only be used in pairs, unless a separate switch is used with each instrument to reverse the poles of the battery. But

in order to remove that obstacle, if the receiver is formed of a small induction-coil instead of the simple one, then an alternating induced current is produced, without using an induction-coil in the instrument. The result of this will be that any resistance in long lines may be overcome by simply increasing the battery power to increase the power of the magnet, the induced current being proportionately strengthened.

(*f*) Communication.—Fig. 126 represents the 2 boards, one at each end of

Fig. 126.



line, fitted with bell *a*, bell-push *d*, telephone, telephone-hook *f*, and terminals for transmitter *b*; also 4 terminals on the top of each for carbon of battery *c*, zinc of ditto *z*, earth *e*, and for line. Note the difference in battery wires in No. I. and No. II. stations. The push *d* is a 3-line push, line and bell being in contact; when pressed, bell is cut out, and line and battery are in contact. The hook is balanced on pivot *f*. When telephone is on it, the other end is in connection with bell stud; when removed, it falls to the other stud, and puts bell out and telephones in circuit. The currents pass as follows:—No. I. to ring up No. II.; *c* to push *d* and line, enters No. II. by line to push, hook, bell, earth, to *e* No. I. to *z*; No. II. to ring back; *c* to *e*, to *c* No. I., to bell, hook, push, line, enters line No. II. to push, *z* and *c*. To speak No. I. to II., unhang telephones each end; *c* to transmitter, telephone, hook, push, line; enter line No. II. push, hook, telephone, transmitter, *z* through battery to *c*, *e* to *e* No. I. and *z*. To reply No. II. to No. I. *c* to *e*, to *c* No. I., *z*, *c*, transmitter, telephone, hook, push, line. Enters No. II. line, push, hook, telephone, transmitter, and *z*.

The following works will be found exceedingly useful to those interested in the subjects of which they treat:—A. Bromley Holmes, 'Practical Electric Lighting;' R. E. Crompton, 'The Electric Light for Industrial Uses;' T. B. Grierson, 'Electric Lighting by Water Power;' Killingworth Hedges, 'Useful Information on Electric Lighting;' T. D. Lockwood, 'Practical Information for Telephonists;' and the article on 'Electrical Engineering' in the Supplement to Spons' *Dictionary*.

Enamels and Glazes.—Enamels and glazes, properly speaking, are opaque, vitreous, coloured materials, tractable in the fire, and used in ornamenting metals and pottery; but it will be convenient to add here a few recipes for so-called "enamels" on other substances.

Cloth.—As a substitute for leather, enamelled cloth is now largely used where lightness and pliability are desirable. Having the appearance of leather, and nearly, if not quite, its durability, it is used where strength is not so important as a good appearance. In the covering of carriage tops, the upholstering of furniture, the covering of trunks and travelling bags, a great quantity is used, and it is also employed in garments, coverings, &c., as a protection from water. The details of its manufacture are very simple.

The foundation of the article is cotton cloth of the best quality, and generally made expressly for this purpose. The cloth is taken from a bale and wound upon a large cylinder preparatory to receiving its first coat. It is then passed between heavy iron rollers, from the top one of which it receives its first coating of composition. In many places the covering is spread by a knife under which the web passes. The composition

is made of linseed-oil, lampblack, rosin, and a few other ingredients, which are boiled together till they reach the consistency of melted tar. From between the cylinders it is carried to a drying frame made in the shape of a reel, and subjected to a high temperature in the drying-room, which is heated generally by steam pipes. After the drying process it is given to workmen, who make all the rough places smooth by rubbing with lump pumice and water. The cloth is then passed through the same operations as before, rolling, drying, and rubbing, and this is repeated 3 to 5 times, or until the required thickness has been laid on. After the last scrubbing down, the fabric is taken to another department, thoroughly varnished, and again passed through the heater. It now appears as a piece of cotton cloth, with one black side looking very much like patent leather. One step yet remains to be taken. The cloth is passed between heavy rollers, which cover its surface with regular indentations resembling the grain of leather. It is now ready for the market. As many frauds are perpetrated in this article as in any other. Manufacturers who desire to turn out a heavy material, first fill the cloth with clay, and the result is an enamel that will crack during the cold weather of winter; or, in their endeavour to produce a cloth that will stand a low temperature without cracking, they make material that will be sticky in summer. The poor quality is used in the cheap trunk and bag trade, but none but the best will do for the outside wear that comes upon carriage tops. (*Manufacturers' Gazette.*)

Dr. Ballard has some valuable remarks on this manufacture in one of his reports. The japan or enamel used for enamelling cloth or leather is usually prepared, he says, by boiling Prussian blue or peroxide of iron in raw linseed-oil. At the Leather Cloth Co.'s works at Stratford, the pots for making it, 16 in number, each holding 150 gal., are set in brickwork and arranged along 2 sides of a building devoted to the purpose. The pots are enclosed in brickwork chambers having sliding iron shutters in front, which can be drawn down during the boiling. The fumes escape by pipes, and are drawn away by a fan, and delivered into the ashpit of the boiler of the works, for consumption, thus preventing nuisance. The pots are fired from the rear, and the enamel is allowed to cool before being ladled out.

The manufacture of leather cloth (American cloth) and of table covers is carried on at some places on a very large scale in extensive factories, and at others in much smaller establishments. The details of the operation may differ in different works, correspondingly with differences in the precise article manufactured and the use to which it is to be applied; but the essential features of the business are the same in all works. The enamelling of leather and pasteboard for the preparation of what is called "patent leather" and the peaks of military and other caps is a very similar process, but is conducted only in small establishments.

The enamel used at the smaller establishments is ordinarily purchased from persons who prepare it; but at the larger establishments it is usually made on the premises. Briefly, the process consists in laying on the varnish or enamel smoothly upon the cloth, &c., and then exposing the varnished material to a high temperature in an oven or heated chamber.

For the making of table-covers, the cloth is usually manipulated in convenient lengths, and the same is mostly the case when leather cloth is made in the smaller establishments for the covering of boxes and cabs. In the large establishments for the manufacture of leather-cloth, the cloth is made in rolls of many yd. in length. In some cases, the cloth undergoes preparation before the varnish is laid on, with the object of preventing imbibition, and sometimes to impart thickness and substance to the article made. This preparation consists either in sizing the surface, and perhaps after sizing putting on a layer of paint, or in laying on at once a paste made with boiled linseed-oil, whiting, and

water. When the surface thus prepared is dry, the varnish is laid on. When a long roll of cloth has to be varnished, the varnish is spread on by means of a machine adapted to the purpose, which puts it on smoothly and evenly as the cloth passes through it, and as the cloth leaves the machine it goes on directly to the drying chamber. When the cloth is varnished in lengths, it is laid upon a long smooth table, and a workman lays the varnish on evenly by hand, using for the purpose a flat instrument or scraper. After being varnished, it is hung up in a drying-room, the capacity of which varies of course with the size of the works. The larger establishments have several such rooms, a considerable extent of the buildings being thus occupied. The room is heated to about 170° F. (77° C.) by means of steam pipes or hot-air pipes, or by means of heated air driven in by a fan, and is ventilated by means of windows the sashes of which can be opened, or by means of an unpointed tiling to the roof. Much vapour strongly impregnated with acrolein is given off and fills the chamber, rendering the atmosphere very irritating to nose, eyes, and respiratory organs. Some of the vapour condenses as a brown liquid on the walls and panes of the windows. It is a common practice to keep the windows closed at night, and to open them in the mornings for the thorough ventilation of the room. In small establishments, instead of a lighted room, a small but sufficiently capacious dark chamber, more of the nature of an oven, heated in the same way or by hot-water pipes, is in use. The iron doors of such an oven open into the room where the varnishing operations are carried on, so that the atmosphere of this room in which the men work is always more or less charged with irritating vapour. Such an oven as this, if ventilated at all, is ventilated by means of a pipe proceeding from it through the roof of the building.

The process of enamelling leather or pasteboard differs very little from that of making table-covers. The enamel is laid on by means of the scraper before mentioned, and by rubbing it gently on by the hands of the workman. The material is then heated in an oven such as has been described, but so arranged that the material is slid in horizontally upon the sliding shelf on which the varnishing is performed. The varnishing and heating are repeated as often as may be necessary to ensure the proper thickness of enamel.

Brattice cloth, for use in mines, is made at Marsden's factory at Manchester by covering coarse hempen cloth on both sides with a coarse black paint or varnish made of boiled oil and lamp-black. It is then dried in a chamber heated to about 120° F. (49° C.) by means of steam pipes. The evolution of irritating vapour is such that it is said that the windows have to be left open for ventilation for 2 hours before the workmen can enter to remove the cloth.

Such trades as these, unless carried on with due precaution, are apt to give rise to almost intolerable nuisance. The two ordinary sources of nuisance are the manufacture of the varnish and the escape of the pungent acrolein vapours from the drying-rooms and ovens into the external atmosphere. In those works where the only ventilation of the oven is into the workshop itself, when the oven door is opened, although the workmen suffer from the vapour more than they ought to do, the neighbourhood suffers less, probably because much of the vapour is condensed by the cool air of the workshop. The mode of preventing that part of the nuisance which proceeds from the manufacture of the varnish, has already been described. At the Leather Cloth Co.'s Works at Stratford, the nuisance proceeding from the escape of vapour from the drying-rooms has been thoroughly obviated by carrying a 10-in. iron pipe from within each room, at its outer wall, down the outside of the building, to a main underground flue, which enters the main flue of the boiler furnace at a point where the flame can reach the vapour, and consume it before

it is discharged from the chimney-shaft. A fan may be used to assist the draught.

Metals.—In enamelling metals, the enamel is fused by heat upon the surface of the object, and is incorporated by fusion with its surface. Enamel for metals must therefore be indestructible by heat. There are two kinds of enamel, the transparent and opaque; the first is the base of all the coloured enamels, which are produced by adding some metallic oxide to this transparent flux. The transparent enamel is produced by fusing the following materials, which are first ground, then dried, fused, and again ground for use:—3 parts silicious sand, 1 chalk, 3 calcined borax; or, 3 parts broken crystal glass, 1 calcined borax, ¼ nitre, 1 diaphoretic antimony (well washed). Dead white enamel, or calcine, is produced by calcining 2 parts zinc and 1 of lead together. The calcine, or combined oxides, is mixed up with crystal and manganese in the proportion of 1 part combined oxides or calcine, 2 fine crystal (glass) powder, 40 manganese. These are ground together and fused; when fusion is completed, the vitreous mass is poured into water, ground, and fused anew, and this operation is repeated several times, and much care must be exercised, for the smallest portion of oxide or copper will spoil the enamel completely. Other colours are obtained by adding to the transparent ground enamel the following materials, according to the colour desired:—Blue enamel, by adding oxide of cobalt or some of its combinations, with the addition of a little nitre. Black enamel, by peroxide of manganese or iron and a little cobalt. Clay produces, with about ⅓ protoxide of iron, a fine black enamel (clovet). Yellow enamel, by phosphate or sulphate, or some preparation of silver, or oxide of lead and antimony. Thus, 1 part white oxide of antimony, 2 to 3 white lead, 1 alum, 1 sal-ammoniac. Green enamel is obtained directly from oxide of copper or oxide of chromium. Red enamel is more difficult to secure than many others. The protoxide of copper is used in a hydrogen or carbonaceous flame, so as to keep the copper from peroxidizing, or the preparations of gold, *e.g.* the purple of Cassius. Violet enamel: by adding peroxide of manganese and a little nitre, any shade of violet to amethystine colour, or even black, can be obtained. Enamelling is performed in an oven or by lamp. (*Building News*).

Copper.—In Germany and France the following process has lately come into use, especially for enamelling copper culinary vessels:—12 oz. white fluorspar, 12 oz. gypsum, 1 oz. borax, are finely powdered, intimately mixed, and fused in a crucible; the mass produced is poured out, allowed to cool, and rubbed up to a paste with water. The paste is then brushed over the inside of the vessel to be enamelled; after thorough drying, the vessel is gradually heated till the enamel fuses. The coating thus produced is firmly adherent to the copper, is white and opaque, does not easily chip off, and is proof against vegetable acids. It also gives a beautiful alabaster surface for ornamental purposes. (*Ding. Polyt. Jl.*)

Dial-plates.—Dial-plate enamelling includes the manufacture of watch and fine clock dial-plates, with fluted plates for enamel painting, and is divided into 2 branches—hard enamelling, and soft or glass enamelling. In the first branch, the Venetian enamels only are used; in the last, the English or glass enamels. The practice of hard enamelling requires more skill, time, and labour than the others, and is consequently esteemed the most. In preparing the metals to be enamelled on, whether they be of gold, silver, or copper, the process is similar, and one description will suffice for the whole; and first of the making of watch-dials.

The copper plates having been prepared to the necessary shape and size, and an edge raised round the holes, and on the outside circumference, to prevent the enamel from spreading when it is in its soft state, the coppers are then thrown into a pickle-pan in order to free them from any impurities which

may be on the surface. This pickle is composed of oil of vitriol, sufficiently neutralized for the purpose with water; or diluted nitric acid may be used. The coppers being thus prepared, the next step is that of enamelling. When the operations of hard enamelling and glass enamelling are dissimilar, the difference will be described; but to a certain extent they are the same. The enamel as it comes from the maker is generally in small cakes, 4 to 6 in. in diameter. In preparing it for use, a small hammer is used, having one end flat and the other of the shape commonly employed to rivet with. With this the enamel is broken into thin pieces or flakes, by striking the edge of the cake smartly as it rests upon the fore-finger of the left hand. The pieces are then put into an agate mortar, and with a pestle of the same material are finely pulverized, the splinters being prevented from flying about by keeping the enamel covered with pure water all the time the process of grinding is going on. The point at which it should be discontinued can only be ascertained by experience, as the different kinds of enamel and the different modes of its application require the ground enamel to be either more or less fine. In general, it may be stated that the "backing" should be much finer than the first coat, the second coat of an intermediate fineness, the hard enamels considerably finer than the glass, and the flux somewhat finer than these, as the first operates with much less effect on the flux than upon either of the former substances.

When grinding, great care must be taken to keep the enamel free from dirt, and the light flue which arises must be washed away, 3 or more times as may be necessary, in the course of the operation, till the water comes off quite clear. A small teapot is commonly used to pour the water from, and when the enamel is ground sufficiently, the produce is emptied into some other small cup for use, the surface being kept just covered with water. The manner in which the grinding is performed is by pasting the mortar upon the work-bench, on a coarse piece of flannel or linen, twice or thrice doubled and wetted to prevent its slipping. The handle of the pestle is then grasped firmly about the middle with one hand, and the palm of the other being placed upon the top, the operator inclines the upper part of his body over the mortar, and crushes the enamel by pressing forcibly with his breast upon the hand which covers the pestle. The motion is repeated in quick succession, till all the larger pieces are reduced into coarse uneven grains, which grains are afterwards ground to the necessary fineness by holding the mortar firmly down with one hand, and with the other giving a circular direction to the pestle, using at the same time as much strength as can conveniently be exerted.

In enamelling watch-dials, many coppers are usually prepared to go on at once—that method possessing the threefold advantage of saving time, material, and labour. After the enamel has been ground, and the coppers cleaned by means of the pickle, and carefully brushed out with water, they are spread face downwards over a soft half-worn cloth, or smooth napkin, and a thin layer of hard enamel—called in its ground state the "backing"—is spread over the under sides with the point of a quill, properly cut for the purpose, or with a small spoon. The coppers are then slightly pressed on by another soft cloth or napkin, which, by imbibing some portions of the water, renders the enamel sufficiently dry to be smoothly and evenly spread with the rounded side of a steel spatula. The water is then again dried out by the napkin, and a yet further evenness produced by going over the enamel as before with the spatula; and these operations are continued till the back becomes completely smooth, and the enamel is of an equal thickness all over. It must be observed that the water should not be entirely absorbed, as in that case the enamel would fall off in powder before the subsequent operations were completed. When the enamel is properly spread, the loose particles are carefully cleaned away from the edge and hole, or holes,

in the coppers; from the former by the spatula, from the latter by twisting around it the pointed end of a quill; and the process of laying the bottoms is thus finished. Some slight variations from the above method are in use among different artists, but the difference is scarcely important enough to require description. In some instances the enamel is laid on the spatula itself, and the coppers, instead of being held between the fingers, are placed on a round pin by means of the centre holes, till the backs are duly spread. In both modes due care must be taken that the coppers are not bent out of their proper forms.

The next operation is to lay the "first coats"; that is, to spread a layer of glass enamel over the upper sides of the coppers. In doing this, the surface is first brushed slightly over with a small camel's hair brush, or a hare's foot, to remove any dirt or extraneous particles of enamel, as the mixture of any hard enamel with the glass would infallibly spoil the work. The glass is then spread upon the copper in a layer, the thickness of which is commonly the same as the height of the projection round the edge of the copper, and round the edge of the hole. The water is afterwards slightly absorbed with a clean napkin, smoothly folded, and the enamel spread by a thin flat spatula, till all the unevenness is removed, and the surface lies regularly from the edges to the centre. The edge then being gently tapped 2 or 3 times at different places with the spatula, the water rises towards the top, and is again dried off with the napkin, when the enamel is once more made smooth by the spatula, and the water being wholly taken up by the napkin, or as nearly so as can be effected without disturbing the enamel, the first coats are placed upon rings for firing.

The rings employed in enamelling are generally made of a mixture of pipe-makers' clay and Stourbridge clay, rolled up in the form of cylinders, and turned in a lathe by means of a cylindrical piece of wood forced through the centre of the mass when wet. Each ring is about $\frac{1}{4}$ in. in thickness, and the same in depth. The upper side is prepared for use by rendering it slightly concave, which is done by rubbing it carefully upon a half-globe of lead, sprinkled over with fine sand. The under side is nearly flat. Through the convexity thus given to the rings, the edge of the copper or dial-plate only is suffered to touch, by which means the enamel on the back is undisturbed, and the edges are prevented from sticking by rubbing over the surface of the rings with soft chalk or whiting.

The "first coats" having been placed carefully on, the rings are next put into a shallow tin vessel, called a tin cover, which is either made square or round, according to the fancy of the workman, and is commonly about $\frac{3}{4}$ in. in depth. All the moisture is then slowly evaporated from the enamel by placing the cover upon a stove, or in some other convenient situation near a fire, where the evaporation can be conveniently regulated; for, should the water be dried off too quickly, the work will be in danger of spoiling from "blebs or blisters." These are very small air-bubbles, which, by rising to the surface of the dial-plates, destroy their smoothness and beauty. They appear to be occasioned partly by want of due care in laying on the enamel, and partly by the confinement of the air that the water contained, which, in the process of firing, becomes rarefied, throwing off by its expansion a portion of the surrounding enamel, yet not entirely escaping without a vivid heat, and even then resolving into black or green specks, so coloured by the oxidation of the copper.

The firing is executed beneath a muffle placed in a small furnace ignited with coke and charcoal. The furnace being brought up to a sufficient degree of heat, the first coats are taken separately from tin covers, and placed upon thin planches of clay or iron, chalked over, and gradually introduced beneath the muffle, where, in a very short time, the enamel melts; or, to speak technically, it "runs," and on becoming properly consolidated, the first coat is com-

pleted. Great attention is required in this operation to prevent the enamel from being over-fired, as in that case the glass would lose some portion of its opacity, and other defects also be produced, to the detriment of the work. The planches are placed towards the further extremity of the muffle by means of a pair of spring tongs, and as soon as the fusion seems to take place, are turned carefully round, in order that every part should be equally fired. The planches are generally made circular, and slightly concave, for the convenience of moving the work without danger of shaking off the enamel before it becomes fixed by the heat.

As all solids, when reduced to a granulated state, occupy a greater space than before, it will be found that a very considerable depression takes place in the enamel of the first coat by the action of fusion. This deficiency in substance it is the office of the "second coat" to supply. When the work is cooled, therefore, the scale is wholly removed, on the projection round the edge of the copper and round the holes, by means of a smooth file or by a piece of greystone, and being then washed and dried, each plate is put upon a small round wax block of sufficient bulk to be held in the hand, and about 4 or 5 in. high. The feet of the dial are then either pressed firmly into the wax which covers the end of the block, or the plate is otherwise fixed by means of 3 small cones of wax placed triangular-wise on the block, care being taken not to spread the enamel by too hard a pressure. A second layer of ground enamel is then gently spread with a quill, and prepared for firing by the napkin and spatula as before, after which the "second coats" are replaced upon the rings, and, the moisture being evaporated in the tin cover, they are ready for a second fire. It should have been mentioned that one edge of the cover, both in this and the preceding operation, should be left a little open to give issue to the steam.

The second firing requires equally cautious management. The plates must not be over-fired, nor must the heat be suffered to melt the enamel too rapidly, but a kind of rotary motion—technically called "coddling"—must be given to the work, by holding the loaded planch lightly with the tongs, and gently drawing the edge of it towards the mouth of the muffle, and then returning it to its former place till the fusion is complete, a proper knowledge of which can be gained only by experience. The work is now in a fit state for polishing.

Polishing in the art of enamelling has a twofold significance. It not only means to render bright—according to the common acceptance of the term—but also to make even, without any reference to glossiness. The enamel has a natural brightness of surface acquired from the fire, and when this is removed it is only necessary again to expose it to due heat to cause it to assume its former lustre. Yet as this brightness exists independently of evenness, and as evenness is essential to the perfection of enamelling, it is requisite in most cases to produce that quality by the method next to be described.

The materials used in polishing what are technically known as "glass plates," are greystones, ragstones (sometimes called burrs), bluestones, and fine silver sand and water. The plates are first taken separately, and the thin edges are ground off by one of the greystones till they become smooth and equal. Either the greystone or the ragstone is next employed, according to the nature of the work, to grind away all the irregularities which may be on the surface of the enamel, the ragstone being principally used for the more common kinds of dial. This is done in different ways: first, either by holding the plate upon the fore and middle finger of one hand, and giving it a sort of circular motion by means of the thumb, while with the other hand the polishing stone is rubbed with a forward and backward motion over every part of the surface; secondly, holding the polishing stone on the work-bench with one hand, and with the other rubbing upon it the face of the enamel; or,

thirdly, by fixing the plate upon a cork, either by means of the feet or with a piece of wet flannel, and with the fingers giving it a kind of a rotary motion while the polisher is rubbed over it in a similar manner. The ground silver sand is used to give sharpness to the polishing stones, and wear away the enamel with greater celerity. The act of polishing is continued till all the gloss is ground off the surface. In this operation care must be exercised that the pressure is not too powerful, as the plates will crack in the fire, and can never, or very rarely, be properly mended.

When the enamel is sufficiently polished, which can easily be known by the criterion of all the gloss being removed, the plates must be clean washed, and all the specks of dirt, &c., picked out with a sharp graver. They are then well rubbed over with some fine ground glass enamel, either by means of a cloth, or perhaps a small piece of firwood cut smooth, in order to remove the stains that may be left by the polishing stones, and, clean water being suffered to run over them, they are wiped dry and placed on rings for firing, as described. The degrees of heat necessary for glossing plates are determined by the fine or coarse modes by which they were prepared, as the fusion is much facilitated by the enamel being free from scratches. When the surface is properly run—*i.e.* when it becomes perfectly smooth, even, and bright—the plate is completed, and when cold, is fit for painting on. The above description refers more particularly to the best kind of work. There are two other modes of enamelling watch-dials, which it will be required briefly to explain. The plates made by the following methods are called technically "run-down plates," and "run-down second coats."

Run-down plates are those which are made by laying enamel upon the copper in sufficient quantities to form plates of the required thickness without putting on a second coat. Both labour and fire are thus saved, but the neatness, regularity, and squareness obtained by the first method are scarcely obtainable in this; and indeed flat plates can hardly be managed at all by this mode. Running-down plates require more "coddling" than the others, and a longer continuance of vivid heat is necessary to make the glass flow to a proper evenness of surface, the plates being wholly completed with one heat and without polishing. It is obvious that only common work can thus be manufactured. For work of the next superior description, the run-down coats are polished off with the ragstone and undergo a second firing. The run-down second coats are those which are reduced to a comparatively even surface by a second firing, and then painted on without being polished off.

In enamelling hard plates for watches, the coppers and the first coats are prepared in the manner already described, excepting, perhaps, that the layer of glass is rather thinner than in glass work only. The hard enamel, which used to be much valued on account of its rich cream colour, is broken down and ground in the same way as the glass, if only a small quantity is wanted; but if otherwise, it is first broken from the cake with the hammer, and then pounded in a steel mortar till reduced to coarse grains. These grains are then exposed to the action of a magnet, in order that all the particles of steel that have been broken off the mortar in the act of pounding may be taken away, as they would infallibly spoil the work by rising in black specks to the surface of the enamel when exposed to the fire. As an additional precaution, it is also necessary to put the granulated enamel into a small basin, and pour upon it a strong solution of oil of vitriol, or aqua-fortis, and allow it to stand for some time, so that any steel particles which may be in the enamel may be completely dissolved. The enamel must then be very carefully washed till the water comes off pure and tasteless, for should any acid remain, the work would certainly blister.

The enamel is then ground to the necessary fineness in an agate mortar, as

previously described, and afterwards spread over the first coats with a quill in small quantities, and as evenly as it can be laid, so that it may require the use of the spatula as little as possible. The water is then partly absorbed by a very fine, clean napkin, and the enamel is smoothly spread and closely compressed with the spatula, after which more water is absorbed, and the spreading is continued till the surface lies true and even. The plate is then put upon a ring and properly fired, and is afterwards polished by placing it upon a cork and grinding the surface, first by a fine file, or a smooth piece of steel with silver sand ground to an almost impalpable powder; secondly, by a fine bluestone and sand; and thirdly, by the bluestone alone. With the latter, a sort of half-polish should be given to the enamel, and the higher that polish approaches to complete glossiness the better, as the plate will then be finished in the fire with a less degree of heat than would otherwise be required. In this process, much caution is required to prevent scratches, which cannot be "run up" by the fire without giving the enamel a greater degree of heat than it will bear. It should be mentioned that before polishing the face of the dial, the top edges should first be taken off with a fine greystone.

When the polishing is completed, the plate is carefully cleaned with ground enamel, and should there be any specks, they must be picked out with a small sharp diamond, and the hollows very dexterously filled up with enamel from a quill point, so that they may neither rise above nor sink below the general surface when the plate is again fired. Should they actually do so, they must be made smooth with a bluestone, and the plate must undergo a fourth firing to render the surface of uniform texture and glossiness. Hard enamel dials are always considerably more expensive than glass enamel ones, through the greater labour, attention, &c, that is requisite in making them. In the polishing off of both hard and glass enamel dial-plates, much care is required to prevent a separation of the enamel from the edge of the copper; for if too great a pressure is exercised, or if the stones which are employed to grind down the copper are too rough in the grain, the adhesion will be destroyed, and various black indents will arise round the edge of the enamel when the plate is again exposed to the fire. In glass enamel dials these defects may sometimes be amended, but in hard enamel dials scarcely ever.

These directions for enamelling watch-dials may be concluded with some general observations upon the accidents that are most likely to occur in both kinds of enamelling, and in pointing out the best methods to remedy them when they do happen. When good Venetian enamel cannot be obtained, and mixtures of various kinds are resorted to, it frequently happens that the glass enamel plates crack when they are brought to the second fire. This is due to the unequal expansion of the 2 enamels, and when the cracking takes place at the top, or upper part of the plate, it requires very delicate treatment to preserve the dial from being completely spoiled.

To do this successfully, as soon as the crack is observed the plate must be withdrawn from the fire, and if the crack extends only from the centre hole to the edge, it will in most cases bear mending; but if it has cracked in 2 or 3 places, it will be useless to make the attempt, as it will rarely succeed. If the dial-plate were to continue in the fire a sufficient time after it was cracked, the enamel would close, and the plate become sound again. But as the copper on its surface is in a state of oxidation, the copper oxide uniting with the enamel would rise to the upper surface of the plate, producing by its union a joint, and sometimes a dark green line, which would evidently render the plate useless. The operator must then observe the time when the crack has opened to its greatest width, and before it unites or closes at the bottom, the plate must be withdrawn from the fire and allowed to cool. The opening must

then be filled with fine enamel, laid sufficiently high to allow for its running down in the fire; but to adjust the quantity so as to prevent the appearance of a seam across the plate, will require much judgment; and indeed, however well the operation may succeed, it will still remain visible, because the new cement cannot be submitted to the process of "using off," as the plate would by such means be rendered very porous in some parts, and thereby attract dirt when the fingers touched the surface.

Another very common accident in making glass enamel plates is to "overfire" them, as it is technically called. Whenever this happens, the arsenic, which gives whiteness and opacity to the material, is converted into a flux by the extreme heat, and that part of the plate which has been so treated becomes semi-transparent and of a light-blue colour. The only method that can be used in that case, is to return the plate into the fire, and give it a longer continuance of heat, but as slight as possible, just keeping it red-hot; and to do this conveniently, the plate should be placed near the front of the muffle, as the greatest heat is always at the back. This treatment will restore the plate to a tolerable degree of whiteness by reviving the powers of the arsenic, but it must never be expected to look as white as if it had been properly fired at first. Should any crack appear on a hard plate, it would be in vain to try to mend it, for as the shape of a hard enamel dial can be brought to great perfection when all parts of the process succeed, it is almost needless to say that the plate would suffer so very much in this point as to render it good for nothing; therefore, an accident of this kind in hard enamelling is always regarded as the close of an abortive attempt.

Transparent Enamelling.—The operations of transparent enamelling are nearly similar to what has been already described in enamelling dials As the work is generally of a more minute kind, greater delicacy of handling is perhaps required, and as the enamels are of various colours and descriptions, more cups, vessels, &c., and additional soft cloths or napkins, are needful to keep and apply them. Watch-cases are usually enamelled upon gold, as well as most of the superior articles of jewelry, and the surface of the gold is frequently engraved in different figures and compartments before the enamel is laid on, by which means the work affords a beautiful variegated appearance. In enamelling the back and edges of watch-cases, &c., quince water is frequently used as the medium by which the enamels are laid on; this, possessing a more adhesive and retentive quality than common water, helps to prevent the enamels from flowing from their proper situations, for when the convexity is considerable, the enamel will of course have a tendency to float towards the lowest part. When enamels of different colours are intended to be employed on the same article, which is frequently the case in ornamental work, small edges or prominent lines are left in the substance of the metal, for the purpose of keeping the enamels separate, and these are polished with the enamel, and reduced with it to a similar equality of surface. Transparent enamels are not unfrequently polished to complete glossiness without exposing them to an additional fire. In these cases the work is finished with rotten-stone.

It is sometimes desirable to remove the enamel from a watch-case or a piece of jewelry without injuring the metallic part. For this purpose, it has been recommended to lay a mixture of common salt, nitre, and powdered alum upon the enamel required to be removed, and afterwards to place it in the furnace; and when the fusion has commenced, to throw the watch-case or piece of jewelry suddenly into water, which causes the enamel to fly off in flakes.

In ornamental transparent work a very pretty effect is produced by applying small and very thin pieces of silver and gold, cut or stamped in different figures—acorns, oak leaves, vine leaves, bunches of grapes, &c.—upon the surface

of the first coating of enamel, where they are fixed by the fire, and are afterwards covered over by the second layer, through which they appear with considerable beauty. When any quantity of fancy work or similar design is wanted, this mode of enamelling is considerably cheaper to execute than to have the surface of the metal itself engraved in the required forms.

Iron.—(1) Enamelling inside of Iron Saucepans.—The article is first cleansed from all oxides by placing it in an acid solution, then dried, after scouring with sand to a grey colour, which shows it to be perfectly clean; apply a solution of gum-arabic to the surface, and sift over it a vitreous substance reduced to fine powder, composed of flint glass, soda carbonate, and boracic acid; then heat it to redness by degrees, till the glass is melted upon the surface. It is then allowed to cool gradually (excluded from the air as much as possible) to anneal it. The glaze is made of 130 parts glass, 20½ soda carbonate, and 12 boracic acid, melted in a crucible, cooled, and then reduced to an impalpable powder. (R. W. Hale.)

(2) For Castings.—Consists in treating the casting with dilute hydrochloric acid, which dissolves a little of the metal, and leaves a skin of homogeneous graphite holding well to the iron. The article is then washed in a receiver with hot or cold water, or cooked in steam, so as to remove completely the iron chloride that has been formed. Finally, the piece is allowed to dry in the empty receiver, and a solution of indiarubber or guttapercha, in essence of petroleum, is injected, and the solvent, afterwards evaporating, leaves a hard and solid enamel on the surface of the iron-work. Another plan is to keep the chloride of iron on the metal instead of washing it off, and to plunge the piece into a bath of soda silicate and borate. Thus is formed a silico-borate of iron, very hard and brilliant, which fills the pores of the metal skin. As for the chlorine disengaged, it combines with the soda to form sodium chloride, which remains in the pickle. (*Les Mondes.*)

(3) For cast-iron pipes. There are various recipes for the enamel, depending on the purpose for which it is applied. One for water pipes is as follows: 28 parts by weight of silica, 11 calcined soda carbonate, and 6 lime carbonate. Another is: 34 silica, 11 soda carbonate, 12 chalk, and 11 dried pipe-clay, to which boracic acid or lead oxide can be added when a more vitreous enamel is required. The core forming the inner surface of the pipe—and, if desirable, the mould too—is coated with graphite (blacklead), smoothed, and the enamel, as a powder, paste, or pigment, is applied to the thickness required. The molten iron causes the enamel to soften and firmly adhere to the iron. If it is not necessary that the enamel should not be smooth, the blacklead is omitted. The enamelled pipes are much appreciated in Bohemia; the Municipal Council of Egar have passed a resolution to use no other kind. They are now being manufactured in several works in Germany and Austria. (Bag and Broz.)

(4) For Culinary Vessels.—For enamelling cast- and wrought-iron vessels, the following are the method and materials most generally employed: 100 lb. calcined and ground flints, and 50 lb. borax, calcined and finely ground, are intimately mixed, fused, and gradually cooled. Of this, 40 lb. are mixed with 5 lb. potters' clay, and ground in water to a pasty mass. The vessel, first thoroughly cleansed by means of very dilute sulphuric acid and scouring with sand, is lined with a coating of this about $\frac{1}{10}$ in. thick, and left for it to harden in a warm room. A new coating is next added, prepared from 125 lb. white glass free from lead, 25 lb. borax, 20 lb. soda in crystals, which have been pulverized and fused together, ground, cooled in water, and dried. To 45 lb. of this, 1 lb. soda is added; the whole is mixed in hot water, dried, and finely powdered. A portion of this is sifted over the other coating while it is still moist, and the vessel is then dried in an oven at the temperature of boiling water, 212° F. (100° C.) The vessel is heated in a stove or muffle till the glaze

appears. It is then taken out, and more glaze powder is dusted on the glazed surface already in fusion. This enamel resists perfectly the action of dilute mineral and vegetable acids, as well as alkalies, and does not crack or scale off from the metal.

(5) Coloured.—The ordinary grey enamel (so called) is really not an enamel, but a transparent glaze, the apparent grey colour of which is produced by the surface of iron beneath the glaze.

(*a*) *Grey Mixture.*

	lb.	oz.
Sand	10	0
Red-lead	33	0
Boracic acid	20	0
Cullett (broken glass)	114	0
Soda bicarbonate	16	0
Nitre	1	2
Manganese	0	8½

(*b*) *Grey Mixture.*

Flint	36	0
Boracic acid	24	0
Soda bicarbonate	24	0
Nitre	18	0

(*c*) *White Mixture.*

Cullett	11	0
Boracic acid	7	0
Soda bicarbonate	0	4
Lime phosphate	3	8
Antimony oxide	0	2

(6) For Wall-plates.—Thin sheet-iron is first cut and stamped to the desired shape, the edges of the plate being turned up slightly in the usual way so as to form a shallow tray, the edges serving to hold the enamel in position during the preliminary stages of the process. The plate is then made chemically clean by any of the ordinary processes of pickling and scouring. The ingredients of the enamel should be taken in the following proportions:—White-lead, 12 oz.; arsenic, 2½ oz.; flint-glass, 8 oz.; saltpetre, 3 oz.; borax, 6¾ oz., and ground flint, 2 oz. These are powdered, mixed thoroughly, placed in the crucible, and fused; but before they are cooled, they must be plunged into cold water, which has the effect of rendering the mass very brittle. The cakes of fused enamel are then pounded to about the fineness of coarse sand, washed, and dried. The powder is now ready for use. The plates of sheet-iron, having been well cleansed and thoroughly dried, are sprinkled over with sufficient enamel powder to make the coating of the desired thickness, and are then placed in a muffle, the turned-up edges retaining the swelling enamel in position. Lettering or designs can be produced on the surface by the ordinary means; but if it is desired to put them on when the enamelled plate is cold, they are first received on paper, an impression being taken in soft black enamel from the engraved plate, and subsequently transferred, the article being again placed in the muffle to fuse the enamel of the design or letters. The iron back is more durable than copper, and cheaper. Variations in the colour of the enamel can be obtained by the addition of various salts and earths, such as cobalt, manganese peroxide, iron protoxide, &c., and similar diversity of colour can be introduced into the design or the letters. (F. Edwards & Son.)

(7) Mottled Enamel.—(*a*) The metal is cleaned in the usual way in an acid bath, then, without employing an alkaline bath, it is, after the usual scouring to remove the scale, placed in clear water and allowed to remain at least ½ hour to remove the acid. As soon as it is taken from the water, it is coated with a liquid glaze, placed in the drying-room, and the glaze slowly dried thereon. The appearance and character of the enamel are determined during this drying of the glaze, as, according to the length of the time taken in the drying and to the temperature of the drying-room, so will be the amount of oxidation. No definite rule can be given for either, as the process is affected by many circumstances, as, for instance, the degree of humidity of the atmosphere. The iron ware must be carefully watched during the process, and the temperature and time regulated by its appearance. The glaze is prepared from the ordinary ingredients, taking care to have them mixed and thoroughly smelted together in bulk to expel all

carbon and other elements that would impede oxidation, and in order that the acid in the glaze may have free action. They are then ground in water and applied in the usual way. By reason of the presence of the acid of the glaze, an oxidation of the metallic base takes place freely during the drying process, appearing in and throughout the glaze as reddish spots. This oxidation causes the enamel, when it is finally formed in the usual way by baking the iron in the oven, to assume a mottled appearance. By reason of this oxidation also, the enamel is caused to enter the pores of the iron and become more intimately incorporated with the metal, thus rendering the enamel more durable. Another manner of accomplishing these objects when the use of the ordinary bath is retained, is to increase the borate and reduce the alkaline fluxes in the composition of the glaze, thereby overcoming the alkali and ensuring the oxidation of the metal. This process does not prevent the addition of the usual colouring matter to the glaze. (Niedringhaus.)

(*b*) The composition of the enamel is as follows:—Silica, 100 lb.; soda-ash, 35 lb.; borax, 75 lb.; plaster of Paris or gypsum, 10 to 20 lb.; and arsenious acid in the proportion of $1\frac{1}{8}$ per cent. of all the other ingredients. When these are compounded, the resultant mixture is an enamel, vitreous enough to carry a glaze of itself, with an affinity for wrought or sheet iron which causes it to adhere with extreme tenacity when burned upon it, and which will not exfoliate or absorb moisture in quantity sufficient to destroy its polish. The ingredients of the enamel, having been comminuted, are carefully mixed together, and brought to a state of complete vitrification in a reverberatory furnace, with observance of the rules applicable to glass-making generally. Then the enamel is run off as usual into water to granulate, when it is ready for grinding. In making an enamel for wrought or sheet-iron ware, 100 lb. of the enamel is ground in an ordinary porcelain-mill, adding about 5 lb. clay, preferably white, and having a pronounced soapy feeling, which clay helps to give body to the enamel, and to prevent its crazing when it is finally fixed on the iron in the heat of a muffle. This grinding requires about 1 working day, and should always be continued until the enamel is thoroughly ground, and the clay thoroughly mixed with it. It is advisable to introduce along with the enamel and clay in the grinding process, calcined magnesia carbonate in the proportion of 8 oz. to 100 lb. of the enamel. This salt of magnesia serves to make the enamel coat as finally applied less transparent, contributes to the flecking or spotting of it with white, and thus in a measure prevents the iron base from imparting to the enamel throughout its own dull and unattractive shade. Prepared as above, the mixture is run off through a strainer into tubs, where it is allowed to remain about 1 day, during which time a sort of ripening is effected, when it is finally prepared as follows:—The mixture being brought to about the consistency of cream by the addition, when necessary, of water, magnesia sulphate is added until the mixture is coagulated and pasty, yet still capable of being shaken out into a thin and uniform coat. 2 oz. magnesia sulphate is usually sufficient for 100 lb. of the mixture. The mixture having been finally prepared, the article is dipped into it, having been first prepared by the well-known processes of annealing, pickling, scouring, and washing. For washing, clear water is used, the iron remaining therein until it is dipped. Care should be taken that the enamel be not laid on too heavily, and that it be evenly distributed. Having received a thin uniform coat by dipping, the article is dried, for if the enamel coat is burned while still damp it will crack or craze. This drying is accomplished, for convenience and despatch, in an oven constructed for the purpose, the range of heat in which varies from about 100° to 200° F. (38° to 93° C.), but it may be effected at summer heat in an ordinary close room. The higher the temperature, the smaller and less distinct the spots; the lower the temperature, the more

pronounced the mottlings. The time required depends upon the thickness of the enamel coat, the quantity of moisture present, and the degree of heat employed. When thoroughly dried, the coat is of a whitish colour, and usually either brown or reddish-brown spotted; and when burned in a muffle, is of greyish colour, dark spotted. The burning process is effected in an ordinary muffle at a red, cherry-red, or slightly greater heat, the ordinary time required being about 4 minutes. (Quinby and Whiting.)

Lead.—A method of coating leaden pipes by incrustation with lead sulphide is as follows:—A hot concentrated solution of sodium sulphide is allowed to flow through the pipes for 10 to 15 minutes. They then appear as if coated within with a grey glaze, and water afterwards passed through them remains, it is said, free from lead.

Photographs.—(1) A very good formula for enamelling or encaustic paste is as follows:—Pure virgin wax, 400 parts; gum elemi, 8; benzole, 160; oil of spike, 14. Apply to the surface of the print with a camel's hair brush or a soft flannel pad until a brilliant polish is obtained.

(2) The glass upon which the enamelling is to be done must be scrupulously clean: plate glass, free from scratches, is the best. After being thoroughly cleaned, some powdered talc or French boot-powder must be sprinkled on the plate, and, with a tuft of cotton, rubbed in a circular motion lightly until no traces of the powder are perceived. This gives it a surface which causes the collodion to be easily removed from the plate without sticking. Flow the plate with a collodion made of—

Ether	4½ oz.
Alcohol	3½ oz.
Gun-cotton	30 gr.
Castor-oil	24 drops.

Let it dry, and immerse the prints in a solution of gelatine made as follows:—

Cox's gelatine	1 oz.
Water	8 oz.
Glycerine	50 drops.

Put the gelatine and glycerine in the water, and let stand all night, when it will be ready for use, after filtering, which may be done by warming sufficiently to render it limpid. After immersing for 5 minutes, take out the prints, and place them face downwards on the collodionized plate; then roll with a rubber roller lightly, to press out surplus gelatine and air-bubbles. After the prints have set for an hour, they must be mounted, using gelatine for the purpose, putting it on the back of the print with a brush, placing the mount on the print, and keeping it in place by means of a glass on the back, with a weight sufficient to flatten. It may remain thus some 10 or 15 minutes, after which the glass can be removed, and the whole allowed to dry thoroughly, but without the use of heat. Frequently the prints will come off themselves when dry; if not, by running a knife-blade around the edges they will easily leave the glass. This formula can only be used successfully on cards and imperials by printing the picture on paper a little larger than the mount; and, by masking the picture, print a border to it representing the black mount.

(3) The glass must be coated with an enamel collodion, and allowed to dry, which may be about an hour. Whilst the plate is drying, prepare as much Nelson's gelatine as is likely to be sufficient to cover the quantity of plates you require, in the proportion of 1 dr. gelatine to 3 oz. water. Place the solution in a bottle with a little cold water; in a few minutes the gelatine will swell, and boiling water will make it rapidly dissolve, and be ready for use. The dry collodionized plate must be coated with this gelatine solution, and again be left to dry. When the plate is quite dry, take it in one hand, and the untrimmed print in the other; plunge both into clean cold water, place the face of the print in contact with the film of the plate, and remove both together from the water. Pass a sponge or a squeegee over the back of the print to exclude bubbles and ensure equal contact. It is now necessary to apply the mount to the back of the print. Take a card, and

cut it a size smaller all round than the print. Immerse it in hot water to soften, and afterwards in a solution of gelatine, 2 dr. to the oz. Lay this gelatinized card on the back of the print, and apply a sponge to remove air-bubbles, &c., as before. The plate with the card and print must now be laid aside in a warm room to dry. When perfectly dry, the point of a knife must be carefully run round the print, which can then be brought away from the glass, carrying the collodio-gelatine film with it. The print must now be carefully trimmed, and may be considered finished, though, if desired, it can be mounted by glueing the card support of the print to the mount required. (Gregson.)

(4) The simplest plan, perhaps, is to rub the picture over with encaustic paste, and burnish it. The encaustic paste is made by dissolving white wax by placing the vessel containing it in boiling water, and adding about ¾ of its bulk of turpentine. Add some scent (cloves, say) to cover the odour of the turps, and see that you get the best.

(5) Instructions by which an absolutely perfect surface may be easily obtained, either on mounted or unmounted prints. Nelson's photographic gelatine (Nos. 1 and 2), ½ oz. each; water, 13 oz.; methylated spirit, 1 oz., to keep it. Collodionize the plate as usual. When dry, dip the trimmed plate in the fluid gelatine, not too warm, and lay it flat on the plate; a superfluity of gelatine does no harm. The mounts should have been previously damped by dipping them in water and pressing them in a towel. Whilst the print is lying on the plate, take a damp mount and place *in situ* on the back of it; then with a squeegee give 3 or 4 sharp rubs to and fro, so as to drive out the bubbles, and reduce the enclosed layer of gelatine to the utmost thinness. In 4 or 5 hours the mounted print will leave the glass perfect. If the mounts are made too wet, a separation from the print may occur when dry. If this happens, just float the inside of the mount on the gelatine before applying it. Enamelled prints always look best made convex. For this purpose, use a thin 2 or 3 sheet board instead of the proper mount; when dry, trim and raise in the press. Cut a thin spring of card to place in the cavity behind the convexity, and prevent its collapsing. Mount by running a thin line of glue round the inner edge with a camel-hair pencil, and place under suitable pressure for 10 minutes. If this is neatly done, they ought not to show the faintest scratch when mounted.

(6) The following instructions for "ceramic enamels" were written by Nelson K. Cherrill in the *Photographic News*:—A piece of glass is cleaned with nitric acid, well washed, dried, polished, and coated 3 times with collodion. A plate cleaned with nitric acid has less hold on the film than one cleaned by any other mode, and consequently it is much more easy to get the film off. As to coating the plate 3 times, that means coat the plate, and place the collodion over it 3 times—with the utmost deliberation—so as to obtain a very thick creamy film. Using thick collodion at once does not do nearly so well. The film, when prepared with a thick sample of collodion, is much more apt to become repellent of water (and thereby quite useless for the process) than one made of thin—that is, usual—collodion, flowed over the plate very slowly 3 times, so as to secure a good strong film.

This stage reached, plunge the plate into the bath, without letting the collodion get too much set; if the setting be prolonged, the result is not so good. A "nitrate bath" means a solution of 30 gr. pure silver nitrate in 1 oz. pure water, sunned all the while it is not in actual use, and when used, rendered acid, in the proportion of 2 drops pure nitric acid to ½ gal. solution. The plate remains in this solution till the greasy marks disappear; it is then taken out at once, placed in a funnel to drain not less than 5 minutes, and is ready for the slide.

Arrange the copying camera in the studio so that the light which passes through the negative to be copied comes

only through one of the side lights, and have no reflectors of any kind. Behind the negative, however, place a piece of finely-ground glass, which renders the light perfectly even. Use Dallmeyer's No. 2B lens. With this arrangement the exposure is for 5 to 20 seconds. If the enamel to be taken is of small size, have a mask on the negative, and block out all light except that actually needed, as this enables you to take 4 or 5 images side by side, by simply pushing the camera dark slide a little way each time. The slide is one that goes in sideways, and takes two C.D.V. pictures on one plate, side by side.

The exposure and development of the image are matters requiring the greatest care and attention, as on the complete success of the transparency the whole process turns. The developing solution is made as follows:—

Pyrogallic acid	12 gr.
Glacial acetic	4 dr.
Alcohol	4 dr.

Water to fill a 12-oz. bottle.

In warm weather, this may be more dilute—say, as far as giving 20 oz. water to the same quantity of pyrogallic acid. Then, of course, more alcohol will be needed. This should be made 3 days before it is used, as it is too vigorous in its action at the first. On the other hand, it must not be kept too long, as then it deteriorates in the other direction. These are the characteristics in development which must be obtained in order to secure a good result. The image must develop very slowly; must attain the exact density required at the same moment that it attains the right amount of detail in the high lights; when examined by reflected light, it must not be "filled up" in the dark parts, or at least the "filling up" must only extend to a very few tones, and above the very darkest; when examined by reflected light, it should show, in fact, nearly all the drawing and shading of the subject; while, of course, when seen by transmitted light, it should show up with extreme perfection. Every detail must be there, with a fair amount of density; but heavy blacks are to be avoided.

To secure these conditions in perfection is to secure a first-class enamel, as all the rest is a matter of course. In actual practice, it is best to place the plate on a level stand during the last stage of development, right under the tap; a full stream can thus be turned on at the exact instant at which it is required to stop the action of the developer.

The plate must be well washed at this stage, and the fixing be done with potassium cyanide. Use a weak solution, and carefully avoid pouring it upon the face or other delicate parts of the picture. The washing should be copious, and should follow as quickly as possible on the completion of the fixation.

When the washing is complete, break off a small piece of the film at one corner of the plate, and direct a thin stream of water from the tap on this corner, making it strike on the bare glass. The use of a camel-hair brush here will facilitate raising the edge of the collodion, so that a large jet of water can be got under the film; this being directed in the proper manner by tilting the plate, will effectually loosen the film from the glass. As soon as this is done, restore the plate to the horizontal position, and with a pointed stick, like a pen-holder, break away from around the picture as much film as can well be spared. Clear off the broken pieces with the finger, and give a slight extra rinse under the tap. This must be gently done, as the film is all loose now, and may slip off if you are not very careful. Get about 2 or 3 oz. of water on the plate, holding it quite level, then, bringing the whole over a large dish filled a couple of inches deep with water, lower one end gently into the water, when the film will slip off into the dish without the slightest injury. If protected from dust, the film may be left at this stage quite 24 hours without any injury or deterioration.

The next stage is the toning. To

make up the toning bath just right is an important feature in the process. The procedure is as follows:—Get a 16-oz. bottle, half fill it with water, put it into a saucepan, also half-full of water, and set the whole arrangement on the fire, or over the gas, till the water in the saucepan comes to the boil. If the glass bottle does not crack under this trial, it may be used with safety. Place in the bottle ¼ oz. iridium potassio-chloride, fill it up with cold water, and set it in the saucepan again; this time, however, do not boil the water in the saucepan, but place it where it will keep very hot; shake the bottle occasionally. After about ½ hour, remove the bottle from the hot water, and place it aside to settle and cool; when quite cold it will be fit for use. This solution will remain good any length of time, and possibly even improves by keeping.

To make up the toning bath, proceed as follows:—Place 12 oz. pure water in a bottle; add to this 14 dr. of the iridium solution; shake it up well. Now add, a few drops at a time, and shaking well after each addition, 7 dr. of a solution of gold chloride (strength, 1 gr. to 1 dr.) The bath is then ready for immediate use, but is better after keeping. It keeps indefinitely.

It is particular to note in this place that the solution in the iridium bottle will have a nearly black sediment; this is simply undissolved chloride. When all the clear solution has been used up, more water may be added, and this remainder used in the same manner as the first lot; but care must be taken that too much water is not added, as ¼ oz. of the chloride will not make 2 16-oz. bottles full of the saturated solution, but only about 1⅓ or 1½.

To use the enamel toning bath, proceed as follows:—Pour some out into a clean dish to the depth of about ½ in., stand near to this a large dish filled to the depth of 1 in. with clean water, and also a small dish with pieces of glass in it under water; the glasses may be about quarter-plate size, or such as will be found most convenient. Now take up one of these glasses, and slip it under the film containing a transparency to be toned, gently raise the glass to the surface (at the same time manipulating the film with a camel's hair brush, held in the right hand) in such a manner that when the glass and film on it are lifted out of the water, there will be an edge of film (say) ¼ in. wide lapping over one edge of the glass. The action of the water, as the plate is taken out, will wash this piece or edge of film round to the back of the plate, and, by so doing, will fix the transparency on the glass in a very satisfactory manner. If care be taken that the edge where the film laps over is kept uppermost, or highest, a considerable stream of water may be poured on the film without any danger of it slipping. Having got the film on the glass, it should be rinsed under the tap in the manner just suggested, and the film may then immediately be transferred to the toning bath. To do this, turn the glass over so that the body of the film is underneath, lower it gently under the surface of the solution, and with a brush disengage the lap of film where it had turned the edge of the plate, now, of course, uppermost. As soon as this is done, the film will move off into the solution free of glass, which can then be removed. When the film has floated free for about a minute, turn it over with the brush, and note carefully if the deepest shadows are toned through, so as to give one uniform tint to the whole film. Turn the film over and over, and move it about till this is effected, and as soon as it is so, remove it from the bath by the same piece of glass, used in the same manner—*i.e.* securing the film by making a little piece of it lap over to the back along one edge of the glass. Let the film drain a few moments, and then transfer it to the large dish of clean water. As soon as it is free of the glass in this dish, gently agitate the water with a brush, so as to wash away the toning solution still adherent to the film.

There is a strong objection at this stage to washing the film under a tap—

dish-washing is far preferable, and as little of that as possible should be employed. As each print is toned in succession, it is placed in the same large dish of water. Use one that will take a half-sheet of paper. When all are finished so far, change them one by one into another dish of water, taking up each film with the glass as before described. This is all the washing they are to have. Now proceed to mount them on the tablets. First of all, pour back the toning bath and put away the dish it was used in, then set before you on the table 2 dishes, one filled about ½ in. deep with ammonia solution, and the other about the same depth with clean water.

Formula for the ammonia solution:—

Ammonia solution at 880°	6 dr.
Water	12 oz.

(This must be kept well corked.)

½ oz. of this mixture, diluted with 1 pint of water, makes the bath into which the films are to be plunged.

Get a chair and sit down to the work, as it is far easier to manipulate the films if both arms can rest on the table. Take off your watch and place it before you, so that you can see it as you work. Place in the dish of clean water a clean glass, and on that an enamel tablet, carefully washed previously. Take another clean glass, and with it remove one of the toned films from the dish in which it was washed, and plunge the same into the ammonia bath. As the film enters the solution, take the time by the second-hand of the watch, and withdraw the film when it has been in 20 seconds; plunge it as rapidly as possible into the water where the tablet is, disengage the glass, and slightly agitate the water in the dish, to give the film a sort of wash. Now take up, with the left hand, the piece of glass on which the tablet rests, and raise it about halfway to the surface; then, manipulating with the brush, held in the right hand, bring the film to its proper position over the tablet. By raising the latter very gradually, the film can be laid in its place in this way with the utmost certainty. As soon as the glass is fairly out of the water, place it with one edge raised a little, so as to drain. If the glass is placed at too steep an angle, there is danger that the tablet will slip out, or, at any rate, get disarranged.

It is proper to note in this place, that the tablets, being curved, the films will not lie flat without the exercise of a little care on the part of the operator. Care must be taken to avoid the formation of one ridge or two around the edges of the tablet, but the spare film should be made to lie as nearly as possible equally in all directions. If this is done with care, no puckers or laps will be found in the film when it is completed in the next stage of the proceedings. When the films have got almost surface-dry, the tablets are removed from the glass plates on which they were lifted from the water. To do this, place the plate level, and with a sharp-pointed stick tear away the useless film around the edges of the tablet, slip a thin knife under the tablet, lift it off the glass on to a sheet of blotting-paper, and at once cover it with a large bell jar or other glass vessel, to protect it from dust and accident.

The picture is now ready for burning, and it should at this stage look like a finished enamel, and be as perfect in every respect, in the matter of light and shade and tone, &c., only it will be of a bluer shade of colour than the finished result; but it ought to have the same relative shade of colour now as it is to have in the completed article. The tablet may be burned at once, or left many days, or even weeks, without change.

A gas muffle furnace is preferable for burning the enamels in, to one heated by coke; whichever is used, it should be ready and at the full heat, a clear cherry-red inclining to white, but by no means a full white heat; too much heat is a mistake, as it renders the process unmanageable, and produces no good result to make up for the extra difficulty of work.

The burning is a most delicate operation, and all the care and attention of the artist are required to secure the

result of its very best point; still, with care, 9 out of 10 enamels can be burnt to a successful issue.

Take up one of the tablets and place it on a piece of fire-clay in front of the muffle, but not too near, say at a distance of about 6 or 8 in. The fire-clay should be supported in such a manner as to tip the enamel towards the heat, so that the rays may fall upon it, as near as may be, equally all over it. When it has been roasted in this manner a little while, move it a little nearer, and then a little nearer, examining it each time. As soon as the action of the heat has turned the colour of the film brown in the least degree, it may be dealt with fearlessly; the fire-clay, with the enamel on it, may then be placed level, just in the mouth of the muffle, where in a few moments the film will take all the shades of brown till it gets quite dark all over; now push it into the heat. (A wire set in a wooden handle, and with about ½ in. at the other end bent to a right angle, is a most useful tool in manipulating the fire-clay plates when in the muffle.)

As soon as the plate is in the heat, watch it with great care; it will seem to get perfectly black all over, and then, almost on a sudden, the whites of the picture will be seen coming out quite clear. The moment this takes place, draw the tablet towards the mouth of the muffle, remove it to the outside to cool a little gradually, take the tablet then right away, and place it on wood to get cold. All beauty will by this time have disappeared from the enamel, the whites will stand out, and the few tones next to them will have some clearness; but all the other tones will be a dark and confused mass, hardly distinguishable one from another. This is the true characteristic of a good glaze at this stage. It is now ready to glaze.

The enamel glaze is brought, as prepared for photographic work, from Worcester, where it is made in large quantities. About a thimbleful of the glaze (which is a fine powder like flour) is placed in a small narrow bottle—say a 2-oz. medicine bottle—and the bottle is filled up about ¾ with alcohol. This is marked "Glaze in alcohol." To make up the glazing mixture take a 2-oz. medicine bottle, and put in it ½ oz. uniodized collodion, such as would be used for negatives; add to this ¼ oz. methylated ether and ½ oz. alcohol; now add as much water as it will take without throwing the gun-cotton down; to do this set the tap to drip very slowly; get one drop into the bottle, shake violently, and then get another drop in, and repeat the shaking; so go on till 6 or 8 drops are added, which is about enough. Shake up the bottle of "glaze in alcohol," and let it rest about 2 minutes for the coarser particles to subside, then carefully add some of the upper part of the mixture to the diluted collodion—enough to make it rather opaque and milky-looking will do. This is the glaze ready for use; it must be well shaken up each time it is used.

When the enamel is quite cold, balance it on the top of one finger if small, or near the edge of a piece of flat wood if large, and pour the glaze mixture over it; then immediately tilt the enamel up to the vertical position, letting the glaze run off on to soft blotting-paper, rocking the tablet in the meantime to prevent the formation of lines. When the collodion is set, place the tablet in a muffle on a piece of fire-clay, and gradually introduce it to the full heat; keep a careful watch now to see that the burning does not proceed too far. The glaze should only just melt; as soon as this is the case, which will be seen by looking at the reflection of the bent wire held just above the tablet, pull the enamel out, and when a little cool, remove to a block of wood to get cold again.

The image is now indelibly fixed, and it may be treated roughly with impunity. The picture is not, however, at its full beauty as yet, as, if all the baths, &c., have been in good order, one glazing will not be sufficient. The whites will be glazed, or have a polished appearance, but the darks will be still of a matt surface, and not transparent in effect, as they should be.

This is overcome by repeated glazings. No enamel is perfect that has not been glazed at least 5 times. The number of separate burnings (say 5 or 6), as here recommended, give a totally different effect to what would be obtained by one great burn with the glaze applied thicker. Those who wish to save themselves trouble will work in this way, but any one who wants to get the best results will not mind the trouble of 5 or 6 or even a dozen glazes.

When the glazing comes nearly to an end, there will be found some little points where improvement is needed in the way of retouching. This point is very easily gained. Collect all the trimmings of films after they have been through the toning and ammonia baths, and all waste or torn films as well; place them a few moments in the muffle on a piece of fire-clay—they will instantly burn, and the ash is to be carefully collected, and kept in a small bottle. A little of this may be placed out on a palette, with a minute atom of the glaze powder, and one drop of some essential oil, and then well rubbed down with a muller. The paint so obtained may be used with fine brushes dipped in turpentine, and the work being burnt into the enamel, will take the same colour and surface as the rest of the picture.

Ceramic colours may be applied to enamels, and burnt in with considerable success, but there is much difficulty in getting the red shades wanted about the lips and cheeks right. Use the colours made by Lacroix, of Paris.

When an enamel has failed, it may be put on one side; and when there is a sufficiency of them, the images may be dissolved off with fluoric acid, applied with a rag at the end of a stick, and then, after washing, the tablet may be fired in the muffle till it melts to a good bright surface. If this be carefully done, the tablet so renewed will be as good as new. In this firing, after cleaning, the image will often appear again when in the heat. If this be the case, the heat should be continued till a full glaze has been obtained, when the tablet, after cooling, may be again treated with the acid, and again fired.

When the successful enamel is finished up to the last heating, the name and address of the artist and other matter may be written on the back with a fine brush dipped in the same paint as used for retouching, but a little more thinned with turpentine.

The following are the main causes of failure, which should, however, never be met with by any one who follows the instructions accurately. Failures are of 4 distinct classes, which may be thus enumerated:—I. In development. II. In the direction of getting poor slaty-bluish colours, which glaze all at once when put in the muffle. III. In the direction of excessive blackness, just the opposite to the last. IV. In the glazing operation itself.

With regard to the first, it is imperative that the development proceed slowly—this seems to be the only condition of success. The photographer's knowledge of his business will enable him so to manage the light, lens, exposure, &c., of the film as to secure this necessary condition. The developer given is by no means the only one that will do, though in some hands it succeeds best

The second class of failures arises from there being too much gold in the toning bath, or rather, perhaps, too much in proportion.

The third class arises from there being too much iridium, or too much in proportion. Both these may be avoided by a strict adherence to the formula given.

The fourth class of failure, the only one to be really feared, is the most difficult to deal with. It is much more difficult to describe than to show. The chief thing to avoid in glazing is the getting an unequal layer of glaze on the tablet the *first time*. *Until the first glaze is burnt in, the picture will rub very easily*; therefore a badly-laid glaze will be its ruin, as it cannot be removed. After the first glaze is burnt, the enamel is safe, and any further error in the matter of pouring on the glaze, &c., can be recti-

fied by simply washing it off again under the tap. Then, again, there is a possibility that when too much glaze is used the enamel will spoil by a sinking in of the image. The best remedies for all errors in glazing are to use plenty of alcohol in the collodion and plenty of water, and at the same time the smallest workable quantity of glaze, making more burns of it, but doing less work at each burn.

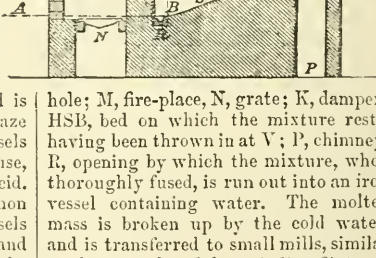
Pottery.—Glaze is a glass built up of 2 or more silicates. The normal felspathic glaze consists of sodic or potassic and aluminic silicates; salt glaze, of sodic and aluminic silicates; lead glazes are mixtures of plumbic with aluminic silicate, and small quantities of sodic and potassic silicates. There are also glazes containing zincic silicate and ferric silicate, and in some cases one silicate is replaced by a borate. Glazes may be rendered white and opaque by the addition of an infusible excess of stannic and arsenic oxides, and may be coloured by metallic oxides, in the same manner as glasses. Glazes are applied by dipping, and by volatilization. The difficulty in preparing a glaze is the regulation of the mixture, so that the contraction of the glaze after fusion shall not be unequal to that of the body to which it is applied. The decorative effect of "crackle-glaze" is obtained by an adjusted disagreement between the body and the glaze. If the disagreement be allowed to go too far, the glaze chips away from the body. The requirements of a glaze are—(1) agreement with body, (2) power of resisting solution and corrosion, (3) purity of colour, (4) power of developing applied colours. The felspathic and sodic silicate glazes are the most durable; the plumbic silicate glaze is liable to gradual decay, which is indicated by the appearance of a beautiful iridescent film. "Smears" and "flows" are glazes applied by volatilization. In the former process, the saggers are washed inside with a mixture of one or more of the following substances: salt, red-lead or litharge, potassic nitrate, potassic carbonate, and china stone. The ware, generally fine stoneware, is exposed in these saggers, and receives a gloss by the deposition and combination of the volatilized mixture. The object of the use of "flows" is to soften or blur the outline of underglaze painting or printing. Ammonic chloride, alum, and chalk, together with one or more of the materials used for "smears," are placed in small biscuit-cups in the saggers, together with the ware. The glass, which is formed by the deposition of the mixture on the ware, partially dissolves the colouring oxide, and softens the general effect. Plumbic silicate glazes are coloured by metallic oxides, and are used for colouring ware. In this way, imitation "crown" ware is often manufactured. A mottled or marbled surface is sometimes produced on ware by instilling differently coloured glazes from a vessel containing several chambers communicating with a composite neck. Opaque glazes or enamels are used to conceal a coloured body. Majolica is generally made of common fire-clay or marl, and is coated with opaque white enamels, upon which, whilst still moist, coloured enamel decoration is applied. Limoges ware is a clay body decorated by the aid of coloured enamels. In Cloissonné ware, the outline is marked out by metallic threads soldered to a metallic body, and the interstices are filled up with enamels. Imitation Cloissonné is produced by painting on a white clay body with coloured enamels, or by forming a raised outline by painting with a mixture of iron and copper dust, hardening the same by fire, and filling in with colour. Palissy ware has a white or coloured body, covered with transparent coloured glazes. Bristol ware is coloured by coloured felspathic glazes. A curious lustrous or glistening effect may be caused by applying coarsely-powdered mica to the surface of ware. Genuine lustre or iridescence is produced by the irregularity of a glazed surface, caused either by decay, or by the adhesion of an almost imperceptible metallic film. Bismuth, gold, silver,

copper, zinc, iron, and platinum are used for this purpose. The metallic salt is generally mixed with some strong reducing agent, and applied to the ware as a paint. The ware is then fired in a reducing atmosphere, the salt is reduced, and the metal is fixed upon the glaze of the ware by heat. For Brianchon's lustre, which is similar to that used at Belleek and Worcester, a mixture is used of bismuth nitrate, rosin, and essence of lavender. If ferric or uranic nitrate be added to this mixture, the glaze of the ware will be tinted by the ferric or uranic oxide, and the effect of the lustre will be heightened. Instead of applying the reducing agent together with the metallic salt, a reducing vapour may be directed upon a pigment rich in copper, silver, or other metals, with similar results. The red lustre of Gubbio ware is due to the action of smoke upon cupreous oxide; it is usually applied to a coloured body. (Spons' *Encyclopadia.*)

There are 3 sorts of glazes—viz. lead, salt, and felspar. *Lead glaze* can be formed in two ways. (1) The biscuit-ware is dipped into a tub containing a mixture of about 60 pints litharge, 10 clay, and 20 ground flint, diffused in water to a creamy consistence. When taken out, enough adheres to give a uniform glazing when re-heated. The pieces are then again packed up in baked clay cases resembling bandboxes, called saggers, with small bits of pottery between, and fired in a kiln. The glazing mixture fuses at a very moderate heat, and gives a uniform glossy coating. (2) The common clay vessels are painted over with red-lead. If the vessel thus painted is exposed to a moderate red heat, a glaze is produced. These red-glazed vessels are most dangerous for household use, since the glaze is dissolved off by acid. *Salt glaze* consists in throwing common salt into the kiln in which the vessels are heated. The salt is volatilized and decomposed by the joint agency of the silica of the ware and of the vapour of water always present. Hydrochloric acid and soda are produced, the latter forming a silicate, which fuses over the surface of the ware, and gives a thin but excellent glaze. *Felspar glaze* may be either ground felspar or a mixture of gypsum, silica, and a little porcelain clay diffused through water. The piece is dipped for a moment into this mixture, and then withdrawn; the water sinks into its substance, and the powder remains evenly spread upon its surface; it is once more dried, and lastly, fixed at an exceedingly high temperature. The coarse stone-ware made at Bristol is glazed by the vapour of common salt, as is also the Staffordshire flint-ware. The last is the best. The yellow glaze is made by mixing together in water, till it becomes thick like cream, 112 lb. white lead, 24 lb. ground flint, and 6 lb. ground flint glass. Manufacturers in this differ. Nottingham black glaze:—21 parts white lead (by weight), 5 powdered flint, and 3 manganese. Another method is to immerse dried pottery in sea-salt, and bake.

Earthenware.—(1) For the glaze, a mixture of borax, Cornish stone, calcic carbonate, flint, and kaolin, is first fused in a small reverberatory furnace, shown in section in Fig. 127: A is the stoke-

FIG. 127.



hole; M, fire-place, N, grate; K, damper; HSB, bed on which the mixture rests, having been thrown in at V; P, chimney; R, opening by which the mixture, when thoroughly fused, is run out into an iron vessel containing water. The molten mass is broken up by the cold water, and is transferred to small mills, similar to those employed for grinding flint and Cornish stone. After prolonged grinding with water, and passing through

sieves of great fineness, it is purified by agitation in a blunger armed with horse-shoe magnets. A proportion of this slip is mixed with a slip consisting of Cornish stone and plumbic carbonate, or an equivalent of plumbic oxide. Into this liquid mixture, contained in convenient tanks, the wares, rendered porous by burning, are dipped; the mixture is kept in constant agitation, and the porosity of the ware ensures enough being taken up to produce a sufficient glaze. Considerable skill is required to dip the different forms of ware in such a manner that the glaze may be equally distributed, and as little surface as possible be covered by the dipper's hand. When the parts that have been rubbed, or insufficiently covered with the liquid glaze, have been retouched, and the ware has been thoroughly dried, it is replaced in saggers, preparatory to the fusion of the glaze. The ware can no longer be packed one piece upon another, as in the previous firing, for the fusion of the glaze would cause the pieces to adhere, and great damage would ensue. The ware is therefore separated by the insertion of props of refractory clay; made in such form that as small a part of the ware as possible shall be touched. The saggers with their contents are built up in a kiln similar to the one employed for the first firing, only somewhat smaller. The saggers, as in the previous case, are made airtight by the insertion of rolls of plastic clay. The firing lasts some 18 hours, and its progress is tested by the removal of pieces of ware similar to that being fired, and previously dipped in the same glaze. The test-pieces are usually made on purpose, and pierced in the centre to facilitate removal. (Powell.)

(2) Silicate of potash or soda at 35° B. may be used either alone or mixed with 20 per cent. of red-lead and 5 per cent. of silica. The thick varnish is brushed over the half-burnt articles, which are then dried and burnt. The same glaze can be used for statuettes, &c., being quite indestructible when properly burnt in. (*Dingl. Pol. Jl.*)

(3) *a.* Silicate of soda at 50° B., 100 parts; powdered quartz, 15; chalk from Meudon, 15. *b.* Silicate of soda at 50° B., 100 parts; powdered quartz, 15; chalk, 15; borax, 10. This is quite free from poisonous ingredients, and is used at the Lanilis pottery, near Brest. (Salvetat.)

(4) For clay tobacco pipes, requiring only moderate heat, so that in burning the pipes will not be baked too hard. (*a*) Make a saturated solution of sugar of lead (lead acetate) in hot water. Dip the pipes in this, or apply it with a brush to the outside, then dry and expose in an open muffle at a low red heat until properly glazed. (*b*) Potassium carbonate, 1 part; borax, 5; melt together in a sand crucible, pour out on an iron plate to cool, powder, and mix into a paste with a little turpentine oil for use. Apply with a brush or clean rag, and heat slowly in a muffle or oven to incipient redness.

(5) White earthenware glaze: 35 Cornish stone, 20 borax, 10 crystal soda, 20 red-lead, $\frac{1}{8}$ blue calx; calcine, pulverize coarsely, and grind with 20 lb. white-lead, 10 lb. Cornish stone, and 5 lb. flint.

Porcelain.—(1) The material used for the glaze is a natural mixture of felspar and quartz, and is known as "pegmatite." Its average composition is—silica, 74·3; alumina, 18·3; potassic oxide, 6·5; calcic oxide, 0·4; magnesic oxide, 0·2; water, 0·3; and it may be approximately represented by the formula $2(Al_2O_3, 3SiO_2) + K_2O, 3SiO_2$. It is therefore an ordinary glass, to which a second equivalent of aluminic silicate has been added, and the transparency of which is destroyed by the excess of infusible material. Each fresh supply of pegmatite is tested in order to ensure a constant result. For use, the pegmatite is first crushed under vertical grinding-wheels turning upon a revolving base. It is then ground with water in a mill with stone runners, and when reduced to a sufficient degree of fineness, is drawn off, sifted, agitated in the presence of magnets, in order to remove particles of iron, passed into a receptacle, and maintained in suspension by constant agitation. During the long

process of grinding with water, great care must be taken to prevent a sudden precipitation of the material, either through the slackening or sudden stoppage of the stones. The tendency to precipitation may be retarded by mixing a small quantity of acetic acid with the water. Into the suspended pegmatite the biscuit ware is dipped, care being taken that no part of one piece remains in the glaze longer than another, and that the thick wares shall be dipped in a thin glaze, and the thin in a thick. The parts of ware which have been held in the dipper's hand are retouched with a brush dipped in the glaze. The wares are replaced in saggers, and the saggers are arranged in the lower division of the oven, the heat of which is more intense than in the biscuit-kiln. The entire absence of lead renders the glaze when fused exceedingly hard and durable; it is bluish in tint, and cold to handle. The grey tint of the body and glaze is due to the reducing action of the atmosphere of the kiln. The glaze is transparent, and rather more fusible than the body, but becomes thoroughly incorporated with it, and, from its similarity of composition, expands and contracts uniformly with the paste. The bases of ware when removed from the saggers are rubbed smooth with sandstone. Owing to the difficulty of manipulating the paste, it is customary to build up elaborate vases from distinct pieces, which are joined together by metallic fittings; this especially applies to feet and handles. (Powell.)

(2) 40 parts Cornish stone, 45 red-lead, 38 borax, 32½ flint, 22½ flint glass, 18 crystal soda, 5 tin oxide, 1 enamel blue; make small, calcine, grind, and mix with water for dipping. (3) 40 Cornish stone, 36 flint glass, 20 red-lead, 20 flint, 15 potash, 10 white-lead, 3 tin oxide. (4) Crystal: 105 Cornish stone, 90 borax, 60 flint, 50 red-lead, 12 crystal soda, 10 tin oxide, ¼ blue calx; this must be considerably diluted for dipping. (R. W. Hall.)

Wood.—(1) In a clean bottle put 1 oz. crushed gum benzoin, add 1 gill proof spirit, lay by in a warm place, well shake the bottle frequently. This is a superfine finish for mouldings and turned work. May be used advantageously on any kind of small work. To use it, if the work be plain, lay on a coat of the glue and water; when dry, paper off, then take 1 part of polish and 1 of common varnish, mix together, apply with a brush, and again paper off when dry. Now take a mixture of brown hard varnish, 5 parts; polish, 1; brush it evenly over the work, the same way as the grain of the wood. When dry, again sandpaper off. Lastly, give another coating of the last mixture, to be followed, when quite dry, with a thin coat of glaze, laid on with a very soft brush. (Smither.)

(2) First, to prepare the work, give it a coat of glue, size, and whiting; when dry, rub down with fine glass-paper until quite smooth. If the wood is soft, 2 coats may be given; then prepare the enamel by putting 2 oz. common isinglass into 1 pint boiling water; when dissolved, pour in 2 oz. flake white, and give the work a coat with a camel-hair brush or fine Turkey sponge, boiling hot. 2 coats may be given if required. When dry, rub down with pumice and felt rubber until perfectly smooth. Having obtained a level surface, proceed to body-up with white polish, using a little flake white on the rubber, then spirit off. This is used in pine bedroom furniture. Any decorations may be put on with a stencil pattern, mixing the colour with white polish.

(3) In speaking of enamel, it must be understood as polished paint on the surface of woodwork, such as doors, &c. Enamelling and polishing is an art which requires the exercise of the greatest care. The work will not bear any hurry, but must go through its regular course; have its proper time to darken between each coat and process; and the rubbing down must be patiently and gently done—heavy pressure will only defeat the end in view. Great care should be taken in the selection of pumice, both lump and ground, as the slightest particle of grit or hard

pressure will scratch. There are several kinds of filling-up colour used and sold by the colourmen, but most of them are of a dark colour, not suited for light work, as they require so many coats of paint afterwards that it defeats its own objects. In practice, it is best to fill up from the first with the same tint of colour you intend to finish with, which will bear much rubbing down without being shady. For all dark grounds which have to be finished with a dark colour, the black or dark filling is the best. The tools and material required are as follows, viz.:—1. White-lead ground in turpentine, and best white-lead in oil. 2. A clear, quick, and hard drying varnish, such as best copal, white Coburg, and white enamel varnish. 3. Ground and lump pumice, or putty-powder. 4. Rottenstone, ground in water or oil. 5. White felt, $\frac{1}{4}$ to $\frac{1}{2}$ in. thick, and of the best quality. 6. Several flat wooden blocks, of various sizes and forms, suitable for getting into corners and mouldings; these must be covered with the felt on the side you intend to use. 7. 2 or 3 bosses, made of cotton-wool and covered with silk. 8. Sponge, and wash or chamois leather.

Mode of Operation.—In order to simplify the description, we will take a plain panel to work upon. If it is new, give it 2 coats of oil colour, mixed in the ordinary way; now mix the white-lead ground in turps with only a sufficient quantity of varnish to bind it with, thinning to a proper consistency with turps. It is as well to add a little of the ordinary white-lead ground in oil, as it helps to prevent cracking. Give the panel 4 or 5 coats of this mixture, leaving a sufficient interval between to allow it to dry well. Let it stand for a few days, until it is hard enough to rub down. When it is ready, you may rub it down, first with a soft piece of lump pumice and water, to take off the rough parts. Now use the felt and ground pumice, and cut it down, working the hand in a circular manner. You will require to exercise much care to rub it down to a level surface, and without scratches. When you have got it down level, if it is scratched or not sufficiently filled up, give it 1 or 2 more coats, laying it on as smoothly as you can, and rub it down as before. If done properly, it will now be perfectly smooth, level, and free from scratches; wash well down, and be careful to clean off all grit or loose pumice. Now mix flake-white from the tube with the before-named varnish, till it is of the consistency of cream. Give 1 coat of this; when dry, give another, adding more varnish to it. Now let this dry hard, the time for which will of course depend upon the drying qualities of the varnish; some will polish in 8 or 9 days, but it is much the best to let it stand as long as you possibly can, as the harder it is, the brighter and more enduring will be the polish.

ERBIUM.—This metal, like didymium, is one of the so-called "cerium group," and is met with to the extent of nearly 3 per cent. (as oxide) in the mineral gadolinite. It has not yet been obtained in the free state.

GALLIUM.—This metal occurs in minute proportions in some samples of zinc-blende. To separate it, the blende is dissolved in sulphuric or hydrochloric acid, or in aqua-regia, and the solution is decomposed by adding metallic zinc. The precipitate contains most of the foreign metals accompanying the zinc. It is treated with hydrochloric acid, and again with zinc in the cold; as soon as the evolution of hydrogen becomes feeble, the solution is decanted, and saturated with sulphuretted hydrogen; the resulting precipitate is filtered off; the remaining solution is warmed, to drive off excess of sulphuretted hydrogen, and fractionally precipitated by sodium carbonate in the cold till the precipitate no longer gives the gallium line in the spectroscope; the new precipitate is dissolved in sulphuric acid, slowly evaporated till the excess of acid is almost removed, and treated for some time with cold water; this solution is diluted, and heated to boiling, when basic gallium sulphate separates out; this is filtered off while hot, and dissolved in a little sulphuric acid; slightly acid solu-

tion of ammonium acetate is added, and sulphuretted hydrogen is passed through to saturation; the solution is filtered, diluted, and heated to boiling; the new precipitate is washed with boiling water, and dissolved in a little sulphuric acid; a slight excess of alkali is added, and the alkaline solution is electrolysed, when metallic gallium is deposited on the platinum pole. To render it perfectly pure, it is treated with warm dilute nitric acid, free from chlorine. The metal possesses some curious properties. It fuses at 86° F. (30° C.), and then remains liquid for many weeks even at 32° F. (0° C.), unless touched by a fragment of solid gallium, when it immediately crystallizes. The molten metal covers glass surfaces with a mirror-like coating, and oxidizes on exposure to the air. The solid metal has a sp. gr. of 5·9, and a blue-white colour; it is tough, and may be cut with a knife. It dissolves readily in caustic potash and dilute hydrochloric acid, and slowly in warm dilute nitric acid; but it is scarcely affected by cold dilute nitric acid, and is not volatile at a red heat.

GLASS.—This article has no pretension to being a general treatise on the manufacture of glass, which would here be out of place, and which is already given in a very complete manner in Spons' 'Encyclopædia'; it aims at conveying a number of useful hints to the many who use glass, as much as to the few who make it.

Breaking.—Easy method of breaking glass to any required form. Make a small notch, by means of a file, on the edge of a piece of glass, then make the end of a tobacco pipe, or a rod of iron of about the same size, red-hot in the fire; apply the hot iron to the notch, and draw it slowly along the surface of the glass in any direction you please; a crack will be made in the glass, and will follow the direction of the iron. Round glass bottles and flasks may be cut in the middle by wrapping round them a worsted thread dipped in spirits of turpentine, and setting it on fire when fastened on the glass.

Coating on Metals.—The following method has been suggested for coating metallic surfaces with glass:—Take about 125 parts (by weight) of ordinary flint-glass fragments, 20 of soda carbonate, and 12 of boracic acid, and melt. Pour the fused mass out on some cold surface, as of stone or metal, and pulverize when cooled off. Make a mixture of this powder with soda silicate (water-glass) of 50° B. With this coat the metal to be glazed, and heat in a muffle or other furnace until it has fused. This coating is said to adhere very firmly to steel or iron.

Coloured.—(1) It is supposed that any one of certain metals, if its condition of oxidation or its proportion be varied, will, in combination with glass, produce the several effects of colour into which white light can be decomposed. Thus, copper, when suitably treated, will produce the effects of blue, green, and red. Metals enter into combination with glass in various ways. The effect of avanturine-glass is due to the suspension in the body of the glass of minute particles of metallic copper. When gold oxide is used as a colouring agent, it often happens that some oxide is reduced to the metallic state, and the result is a glass which, when viewed by reflected light, appears to be of a dull opaque red colour, but by transmitted light, yields a beautiful opaline blue. Opacity is probably due to an insoluble excess of metallic oxide held in suspension in the glass. White opacity is obtained by the use of arsenic trioxide, tin dioxide, lime phosphate, powdered talc, or cryolite. The effect of blackness is obtained by the oxides of iridium, manganese, cobalt, copper, or iron in excess.

Gold to be used in colouring glass is first dissolved in aqua-regia; the solution, together with oxides of antimony and tin, is added to the ordinary ingredients of flint-glass. The ruby colour is in a great measure due to the reducing action exercised upon the gold salt by the stannous oxide. Ruby-glass is usually gathered from the crucible in the form of lumps, weighing ½–1 lb. As it is gathered from the crucible, it is

perfectly colourless, and only acquires its colour after it has been chilled and reheated in the annealing-kiln. The ruby lumps, after having been annealed, are reheated as they are required, and used for casing the flint-glass. Articles are never made of solid ruby-glass, partly on account of its cost, but chiefly because the colour is so powerful that an almost invisible film imparts a rich colour to the article upon which it is spread.

The red colour of copper ruby-glass is due to cuprous oxide, and all substances liable to part with oxygen, and to convert the cuprous into cupric oxide, must be avoided in its preparation. In addition to avoiding oxidizing agents, such as red-lead and manganese oxide, it is necessary to add reducing agents, to counteract such effects of oxidation as are unavoidable. Stannous oxide and iron scales or filings are for this purpose mixed with the raw materials. The ruby colour produced is intense, and can only be used as a casing for colourless glass. The ruby-glass, when gathered from the crucible, is of a pale greenish-blue colour, and, like the gold ruby, requires to be partially cooled and again heated before the red colour appears. If reheating is carried too far, the red is replaced by a dull brown tint. If copper and iron scales be added in great excess, an opaque red mass is obtained.

Cupric and cuprous oxides, when used without reducing agents, produce peacock-blue or green; the result apparently depends on the quantity rather than on the state of oxidation of the copper. A very minute proportion of cupric oxide will give a distinctly blue tint. Ferric oxide (Fe_2O_3), in the presence of manganese dioxide, which parts with its oxygen, and thereby tends to maintain the oxidation of the iron, produces a rich yellow. Ferrous oxide (FeO) gives a dull green; it is obtained either by the oxidation of metallic iron in the crucible, or by the reduction of ferric oxide. Manganese dioxide by itself and in large quantity gives violet. If the mixture be heated too long, the oxygen is driven off, and the glass is rendered colourless. A red is obtained by a mixture of manganese dioxide and ferric oxide. A minute trace of cobalt oxide imparts a deep purple-blue. Nickel oxide produces a deep red-brown. The oxides of chromium are very slightly soluble in glass; a minute quantity gives an emerald-green or yellow colour; any excess remains in the form of glistening crystals in the body of the glass, and tends to its disintegration. Antimony trioxide imparts a faint yellow tint; excess tends to produce opacity. Oxide of cadmium gives a pale yellow. Uranic sesquioxide produces a bright yellow, but its peculiar property of fluorescence, already referred to, gives to the glass, when viewed by transmitted light, a bluish-green effect. Silver oxide, in common with cuprous oxide, possesses the power of staining glass, when applied as a pigment to its surface, and heated. This is a more convenient way of obtaining the yellow colour which silver oxide gives to glass, as, when mixed with the raw materials of glass, and placed in a crucible, it is only with the greatest difficulty that the oxide can be prevented from becoming reduced. If reduced, metallic silver sinks to the bottom of the crucible, and the glass remains colourless.

The metallic oxides necessary for the production of coloured glass, are introduced into the crucibles with the raw materials. Sheets or circles may be entirely gathered from one crucible, or from more than one, so as to produce a glass composed of two differently coloured layers. Copper-ruby and gold-ruby glasses are always treated in this manner, on account of the great strength of the colours. Ruby is often cased upon blue, green, and yellow, as well as upon white; and blue upon white and green. These cased glasses are particularly useful for representing heraldry, as the casing can be removed by abrasion, or by hydrofluoric acid, and the subjacent ground discovered. Splashed or sprinkled glass is produced by rolling the gathered mass of molten glass in small fragments of differently-coloured

glasses; the fragments become incorporated in the molten glass, and expand together with it.

Only 2 transparent glass stains are at present known: a yellow stain, produced by silver oxide; and a ruby, by cuprous oxide, the latter being very rarely used. A stain may be roughly described as a transparent effect of colour obtained by applying certain metallic oxides to the surface of the glass, in the same manner as pigments are applied to canvas or paper, and by subjecting the glass to heat. The stain should be incorporated in the glass, and be as durable as the glass itself. For yellow, either oxide or nitrate of silver is used; the latter is preferable by reason of its solubility and easy manipulation. In either case, it is necessary to employ some finely-divided infusible medium, moistened with water or tar-oil. The media generally used are iron peroxide and kaolin. (Powell.)

(2) The articles made at Venice of black glass are distinguished above all other productions of that sort by their deep black colour, and on this account meet with much favour. Dr. Kayser, of Nürnberg, investigated the composition of a frit from a Venetian glass factory, and also some black glass wares made there. The following were the results:—

(*a*) The glass frit had the ordinary appearance of a frit, and showed under the microscope isolated small pieces of black glass. In hot water, 29·7 per cent. were soluble, consisting of alkalies and salts of magnesia. These were in combination with carbonic acid, chlorine, and sulphuric acid.

The frit contained—

Silicic acid	55·57
Clay	2·08
Iron oxide	1·25
Manganese protoxide	1·80
Lime carbonate	8·88
Magnesia sulphate	3·95
Soda sulphate	3·55
Potash chloride	0·55
Soda chloride	10·66
Soda carbonate	11·85
	100·14

(*b*) A rod of black glass, such as is used for the manufacture of glass pearls, contained:—

Silicic acid	69·69
Clay	1·94
Iron oxide	2·43
Manganese protoxide	11·39
Lime	7·53
Magnesia	1·26
Soda	5·41
	99·65

From the analyses it is probable that the black colour of the glass is caused by the large proportion of manganese in it. To certify this conclusion, a mixture of sand, soda, and powdered manganese ore (to the extent of 15 per cent.) was melted in a Perrot's glass furnace. The glass substance obtained was deep black while in very thin layers, and dark violet when drawn out in very thin threads, as well as in thin splints. Hence, in point of colour, it was exactly like the Venetian black glass. (*Gewerbehalle.*)

(3) Glass may be stained by painting its surface with a fusible coloured glass ground to a fine powder and mixed up with gum-water or turpentine, and, after drying, then heating the painted glass in a furnace until the coating fuses. Collodion, shellac, or spirit-copal varnishes, coloured with one of the coal-tar dyes, can in some cases be advantageously resorted to as a coloured wash for white glass.

(4) The pigments commonly employed for decorating glass and porcelain have hitherto been prepared either by melting the metallic salt, which is generally the nitrate, in rosin (colophonium), or by decomposing soluble rosin soaps with the solutions of these salts, whereby an insoluble resinate is formed, which is first dried and then dissolved, just as that formed by fusion is in oil of turpentine, lavender, nitro-benzol, or some similar solvent. Both these methods of preparation have their disadvantages, the principal being that a considerable quantity of the metallic salt remains undissolved, and when the

resinous mass is dissolved, it is precipitated and lost, or at best is only recovered by a tedious operation. With the help of carbolic acid, these pigments can be prepared without difficulty, and without any insoluble metallic compounds separating, worth mentioning.

Bismuth.—2½ dr. metallic bismuth are dissolved in aqua-regia, and evaporated in a porcelain dish to a thin syrup. When cold, 12½ dr. carbolic acid liquefied by gently warming in hot water are added. It is left standing a few hours, for, if warmed and stirred at once, an energetic reaction takes place, with violent foaming. At the end of this time, it is well stirred with a glass rod and heated awhile in a steam bath, when there will be an evolution of hydrochloric acid vapours. It is taken out of the steam bath as soon as a drop removed on a glass rod will dissolve clear in nitro-benzol. When this point is reached, the mass is dissolved in nitro-benzol or a mixture of nitro-benzol and oil of spike, when the preparation will be ready to use.

Tin.—2½ dr. pure tin are dissolved in aqua-regia, and the solution is evaporated to a thin syrup, then mixed with 12½ dr. carbolic acid in the manner above described. The remainder of the operation is the same as for bismuth.

Uranium.—3¾ dr. uranium nitrate are mixed with 10 dr. hydrochloric acid and dissolved. This solution is also mixed with 12½ dr. carbolic acid, as before, and treated as already described.

Iron.—3¾ dr. iron perchloride are dissolved in pure hydrochloric acid, and any excess is removed by evaporation, so that the solution when cold will have the consistence of a thin syrup. To this are added 12½ dr. carbolic acid; and it is then treated as described under bismuth.

A manganese pigment can be made from manganese chloride, and nickel and cobalt pigments from their chlorides, in precisely the same manner as that of iron is made from its chloride. The finished preparation can be diluted to any desired extent, as the concentration of the original preparation leaves plenty of play for the dilution. The different pigments above described may be mixed with each other to form all kinds of combinations. (Dr. R. Kayser, *Deut. Ind. Zeit.*)

Imitation Gems.— The property of glass to display a variety of tints by the addition of metallic oxides, is made use of for the production of artificial gems. The percentage composition of the base used is SiO_2, 38·10; K_2O, 7·90; PbO, 53·0; Al_2O_3, Fe_2O_3, 1·00. (Powell.)

Weiskopf gives the following formulæ for the frit used in Bohemia for making imitations of some of the precious stones :—

Imitation Agates. — 10 lb. quartz, 17 lb. red-lead, 3·2 lb. potash, 2·2 lb. borax, and 0·1 lb. arsenic. The quantity of chloride of gold added is equal to that obtained from 0·4 of a ducat.

Agate Glass.—10 lb. broken glass is melted, and to it are added 0·15 lb. copper oxide, 0·15 lb. each of the oxides of chromium and of manganese, 0·02 lb. each of oxide of cobalt and nitrate of silver, 0·01 lb. oxide of uranium, 0·4 lb. red argols, 0·3 lb. bone meal. Each oxide is added alone and at intervals of 10 minutes. After heating the mixture for an hour, 0·3 or 0·4 lb. of fine soot is put in.

Red Marble.— 80 lb. sand, 40 lb. potash, 10 lb. lime, 2 lb. table-salt, 1 lb. saltpetre, and 0·1 lb. arsenic. The mixture is melted, and then 25 lb. copper suboxide and 1 lb. saltpetre are mixed in.

Artificial turquoises are made in Paris and Vienna that cannot be distinguished by external appearances from the natural product, and when artistically made can only be distinguished by means of the file, being usually softer. They are made from alumina phosphate and copper phosphate mixed together and subjected to hydraulic pressure. Even in chemical composition they resemble the natural mineral, which is a hydrated alumina phosphate with 2 per cent. of copper oxide. (*Diamant.*)

The primary materials from which the different kinds of artificial stones

are made on the Continent is as follows:—

Pure pulverized quartz	45·7
Pure dry soda carbonate	22·8
Calcined borax	7·6
Saltpetre	3·4
Pure red-lead (minium)	11·8

These substances are thoroughly mixed together, introduced into a Hessian crucible, and heated to vivid redness in a charcoal fire. When the mixture has been thoroughly melted, the product is a transparent crystal glass of very great brilliancy. In order to imitate the various precious stones, certain oxides or carbonates are added to the above ingredients in the following proportions by weight:—

For sapphire, add	0·106	cobalt carbonate.
„ emerald „	0·530	iron oxide.
„ amethyst „	0·265	manganese carbonate.
„ topaz „	1·590	uranium oxide.

According to Donault, a magnificent description of artificial ruby can be obtained in the following manner:—Of the mixture given above to produce the white transparent basis of all these stones, 31 parts by weight are taken, which, finely pulverized, are intimately mixed with 2·30 parts antimony glass and 0·05 purple of Cassius. On cooling this mixture, after being well melted, it sometimes gives a transparent mass, and at others an opaque product. When transparent, it is a brilliant imitation of the topaz; when opaque, it forms a splendid imitation ruby by melting 1 part of it with 8 of the primary material (1st formula given above). The product when taken from the crucible is in the form of a brilliant yellow crystal, but before the blow-pipe it is transformed into a vivid red crystal, having exactly the tint of the oriental ruby. (Elsner.)

Cutting.—(1) Annealed glass vessels may be subjected to a variety of processes after they have become cold. The mark of fracture left at the base of a blown-glass vessel by the working-iron, is removed by pressing it upon the edge of a swiftly-revolving stone wheel. After the inequality is removed, the roughness is polished away by substituting a wooden wheel for the stone one. Cutting and engraving are modified forms of the same process. The difference of effect lies in the greater depth of incision produced in cutting. In either process, lathes are used, in which the glass is pressed against the cutting-tools; these are wheels revolving rapidly in a perpendicular plane. In cutting, the lathes are driven by steam, and the cutting-wheels are of considerable dimensions. The actual cutting is performed by iron wheels supplied from hoppers with sand and water. The incisions produced by iron wheels are smoothed by stone wheels supplied with water, and are polished by wooden wheels supplied with water and emery-powder, putty-powder, pumice, or rouge. For engraving, the lathes are usually worked by foot-treadles, and the wheels are of copper, and in some cases do not measure more than $\frac{1}{8}$ in. in diameter. In engraving, it is customary to leave the pattern rough and the ground clear; this arrangement, however, may be reversed, by polishing the pattern with leaden wheels supplied with oil and rouge, and by previously roughening the ground. (Powell.)

(2) Glass can be cut under water, with great ease, to almost any shape, by simply using a pair of shears or strong scissors. In order to ensure success, 2 points must be attended to—first and most important, the glass must be kept quite level in the water while the scissors are applied; and secondly, to avoid risk, it is better to begin the cutting by taking off small pieces at the corners and along the edges, and so reduce the shape gradually to that required, as if any attempt is made to cut the glass all at once to the shape, as we should cut a piece of cardboard, it will most likely break just where it is not wanted. Some kinds of glass cut much better than others, the softer glasses being the best for this purpose.

The scissors need not be at all sharp, as their action does not appear to depend on the state of the edge presented to the glass. When the operation goes on well, the glass breaks away from the scissors in small pieces in a straight line with the blades. This method of cutting glass has often been of service when a diamond has not been at hand, for cutting ovals and segments, and though the edges are not so smooth as might be desired for some purposes, yet it will answer in a great many cases.

Drilling.—(1) For drilling holes in glass a common steel drill, well made and well tempered, is the best tool. The steel should be forged at a low temperature, so as to be sure not to burn it, and then tempered as hard as possible in a bath of salt water that has been well boiled. Such a drill will go through glass very rapidly if kept well moistened with turpentine in which some camphor has been dissolved. Dilute sulphuric acid is equally good, if not better. It is stated that at Berlin glass castings for pump-barrels are drilled, planed and bored like iron ones, and in the same lathes and machines, by the aid of sulphuric acid. A little practice with these different plans will enable the operator to cut and work glass as easily as brass or iron.

(2) Small, rough, refuse diamonds, set in the end of a tin tube, make effective drills for glass.

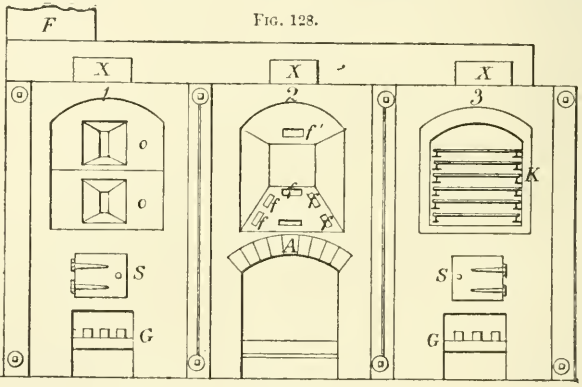
(3) Richter and Co., Chemnitz, have a way of impregnating thin German silver discs (15 to 25 mm. diameter) with diamond, so that when fitted to a quickly-rotating tool, these cut through glass or porcelain in a few seconds, or effect any desired carving with great accuracy. With cylinders made on the same principle, round holes can be quickly and exactly made. The wear of the implement, even after much use, is hardly perceptible.

(4) A simple method of perforating glass with the electric spark is described by Fages. The apparatus required consists (*a*) of a rectangular plate of ebonite, its size, for a coil giving 12 centimetre sparks, about 18 centimetres by 12; (*b*) of a brass wire passing under the plate and having its pointed end bent up and penetrating through the plate (not farther). This wire is connected with one of the poles of the coil. A few drops of olive-oil are placed on the ebonite plate about the point, and the piece of glass to be perforated is superposed, care being taken not to imprison any bubbles of air. The olive-oil perfectly accomplishes the object of insulating the wire. One has then only to bring down a wire from the outer pole of the coil, on the piece of glass, above the point of the lower wire, and pass the spark. By displacing the glass laterally, for successive sparks, it is easy to make a close series of holes in a few seconds.

Enamelling.—An enamel paint may be either an exceedingly fusible glass, covered by some metallic oxide, and rendered opaque by the presence of arsenic trioxide, or an equally fusible transparent glass, mixed with some opaque infusible powder. It is always applied as a pigment, and is fixed to the glass background by heat. It is essentially a glass, and by heat should become partially incorporated with the glass upon which it is painted. There is little doubt that, in former times, artists ground up for their paint some of the self-same glass as that with which they were glazing their windows. Paints formed in this manner require for proper fusion the actual melting-heat of the glass to which they have been applied. The pieces of glass background are therefore usually found to be injured and distorted when removed from the kiln. To obviate this defect, it has become customary to fix the paint by means of a glass very much more fusible than the glass used for glazing. Such may be produced by the addition of a considerable proportion of borax to the raw material of fluid glass, or by the diminution of the proportion of silica in the same glass. One of the first requirements in a window is that it shall keep out the weather. Any decoration, therefore, that happens to be on the outside of the glass, must be

able to resist the action of the atmosphere. Internal decoration is at the same time exposed to the continued action of the products of human respiration, viz. moisture and carbonic acid, as well as to the moisture always present in the air. The borax contained in an enamel paint is rendered anhydrous by fusion, but after lengthened exposure, it re-absorbs moisture, and becomes hydrated and efflorescent. The efflorescence of the borax means the decay of the glass used to fix the pigment to the background. After efflorescence has continued for some time, the pigment begins to flake off, and finally the background is denuded of ornament. Very few of the pigments sold at the present time for the decoration of glass do not contain borax. The use of such pigments upon work intended to be permanent should be carefully guarded against. Flint-glass, rendered more fusible by the reduction of the proportion of silica, is not liable to efflorescence when used as a fixative; care, however, must be taken, in preparing the fixative, that the raw materials are mixed in combining proportions. If there be an excess of any ingredient, decay must necessarily follow. A glass formed according to the formula $PbO . K_2O . 4SiO_2$, which is the same as that of flint optical glass, will be found

FIG. 128.



sufficiently fusible for use as a fixative, and will resist the action of the atmosphere. The legitimate use of enamel paint for the permanent decoration of glass is in the form of a dark-brown or red-opaque colour, for outlines and shading. This is prepared by carefully grinding and mixing with the powdered fusible glass a proportion of ferric oxide, cupric oxide, or black oxide of cobalt. Iridium oxide is also occasionally employed. The colour is applied to the surface of glass in the same manner as an ordinary pigment. Shadows may be represented by 1 of 3 methods, or by a combination of the same: (1) by colour applied in a mass, known as "smear shadow"; (2) by thin lines of colour interlaced, known as "cross-hatching"; (3) by a mass of colour allowed partially to dry, and then disturbed by the action of a soft-haired brush, known as "stipple" shadow. By the last method, the colour is scattered in separate particles, and a certain amount of light is allowed to pass, which gives an effect of transparency. The effect of high light is obtained by removing, with a sharp point, parts of a smear shadow.

The kilns used for burning-in stain and enamel are represented in Fig. 128. 1, 2, 3 may be regarded as the same kiln in different conditions; S is the firing-door; G, the grate; *o*, cast-iron

screens, placed one upon the other, with protruding openings to allow the stoker to watch the progress of the glass within; K, cast-iron casing or muffle, with iron shelves resting upon ridges projecting from the sides of the muffle, upon which the pieces of glass lie; the inside of the muffle is always carefully coated with whiting, and the shelves are covered with a layer of plaster of Paris, in which the glass is imbedded; *f*. openings, allowing the fire to pass from the grate, and through the arch A, in such a manner as to surround the muffle, and to pass off through *f'* into the main flue F; X, soot-doors. (Powell, *Spons' Ency.*)

Engraving.—Planté has suggested a process for engraving on glass by electricity:—The plate is covered with a concentrated solution of potash nitrate, put in connection with one of the poles of the battery, and the design is traced out by a fine platinum point connected to the other pole. The results are said to be of wonderful delicacy. Round articles can be treated by adding gum to the solution to make it adhere.

Etching.—(1) Glass is etched by hydrofluoric acid, or by hydrofluoric acid gas. The gaseous acid has the property of producing a surface which resembles ground glass in its appearance; the liquid acid produces clear etching. Etching glass, therefore, consists of 2 distinct branches—1st, the production of a dull image on a clear surface (when the gas is used); 2nd, the production of a clear image on a surface previously ground or dulled by means of the liquid acid. 1st, the glass plate to be etched is cleaned and gently warmed until hot enough to melt wax. The surface is then covered with an equable layer of white wax, by rubbing the wax over it. When cold, the design is cut out of the wax with a graver. A shallow leaden trough, about the size of the plate (but a trifle smaller) is obtained, into which is placed a small quantity of finely-powdered fluorspar. This must be weighed and then gently sifted over the bottom of the trough. To every 2 parts by weight of fluorspar add 3 of good oil of vitriol. Stir quickly with a wooden stick, and place on the hob or other warm place. Vapour will soon rise. Now remove the trough and cover over with the waxed and graved plate, wax side downwards. In a very short time the acid will have etched the bare portions of the glass. When sufficiently etched, remove the wax by melting. Conduct these operations under a chimney, to carry off the vapours, as they are very injurious. To prepare the liquid acid for clear etching, place 2 parts fluorspar and 3 of sulphuric acid in a leaden retort, the tube of which must dip into a leaden bottle half-filled with water. Apply heat to the retort as long as the water will absorb the fumes generated. If a ground glass be prepared with wax, as above, and a ledge of wax or putty be made round it, on pouring the liquid acid on the plate, clear lines on the dull ground will result; or a "flashed" coloured glass may, by the same means, be made to present a colourless picture on a coloured ground. The sheets of clear glass may themselves be dulled by exposing them, without previously waxing, to the fumes of the acid gas. N.B.—Hydrofluoric acid produces most painful and malignant ulcers.

(2) The etching of photographs on glass is a process little practised by photographers, and yet some pretty applications may be made by ornamenting globes, vases, and drinking-glasses in this manner. It is true some glass is better adapted for the purpose than others, and that which contains a good deal of lead is said to be the most suitable. Any photographic film is sufficiently thick for protecting the glass where the etching liquid is not to act, and designs or pictures may therefore easily be formed capable of resisting the action of hydrofluoric acid, which dissolves the rest of the surface. Glass which is faced with a surface of colour or opal may be worked with great ease, and the acid coming in contact with the unprotected surface dissolves away the facing, and leaves either a design in transparent glass, or one in colour,

according as a negative or positive has been made use of to produce the mask upon the glass. A dilute acid is employed for etching in preference to a strong one, and the time that is required to dissolve away the surface depends in great measure upon the character of the glass itself. A carbon film will suit very well as a mask, and in this case it is well to apply the moist solarized tissue to the glass surface, and develop the image upon the glass. The image, under these circumstances, holds very tenaciously to the glass surface (which has not been waxed, it must be remembered), and, when dry, the glass object is transferred to the etching-bath, where, if it happens to be a lamp globe, it is kept slowly revolving. The etching-bath is made of guttapercha, or wood protected with sheet-lead, and the object remains herein until the etching has proceeded far enough. When this is the case, the glass is withdrawn, washed, and then the carbon or other images removed in any ready manner that may suggest itself. In the case of designs or lithographs which it is desired to etch upon glass, a special ink is employed, which is applied to the surfaces to be protected from the action of the acid. This ink is a thick solution of asphalte in turpentine, thickened by means of beeswax and rosin. In this case, as also in the case of photographs to be reproduced in ground glass or colours, it is necessary that the glass surface to be etched should, in the first place, be of ground glass or faced with coloured glass, blue, red, green, violet, &c., according to desire. The lithographic ink or photographic film forming the design then protects the coloured or ground glass, and the rest of the surface being washed away until the transparent glass underneath comes into view, there results a coloured or ground-glass design upon transparent glass.

Frosting.—Make a saturated solution of alum in water, and wet the glass with the liquid. It is advisable to have the glass in a horizontal position, as the solution is not likely to drain off. The more slowly it is cooled, the more perfect will the crystals be; you can with that intention warm the glass. You may, if you choose, colour the alum solution with cochineal, and of course the more solution you use the thicker you will have the crystals.

Gilding.—(1) Thoroughly clean the glass, then take some very weak isinglass size, and while warm float the glass where you intend the gold to be laid, with the size and a soft brush; then lay the gold on with a gilder's tip, previously drawing it over the hair of your head to cause the gold to adhere to it. Tilt the glass aside to allow the superfluous size to run away, then let it dry, and if it does not look sufficiently solid upon the face, give another layer of gold the same way. Where the black lines are to show, take a piece of pointed firewood, cut to the width the lines are needed, and with a straight-edge draw a line with the piece of wood, which, if made true and smooth, will take the gold off clean, and so square and sharpen up all the edges, lines, &c. When this is done, give a coat of Brunswick black thinned with a little turps, and the lines will show black, and it will preserve the gold. Try a small piece first, so as to get all in order.

(2) The proper flux is anhydrous borax; the real gilding is effected by the aid of heat. For this purpose a solution of gold in *aqua regia* (chloride of gold) is precipitated by potash or green vitriol—a finely-divided powder (brown) consisting of metallic gold. This is washed, dried, and rubbed up with the flux (anhydrous borax). Mix the same with oil of turpentine or gum-water; apply with a brush. When heated in the muffle, the volatile oil escapes; the gum consumed, the borax melts and firmly attaches the gold to the surface of the vessel.

(3) 2 gr. of isinglass; new rum, 2 parts; water, 3 parts. Put the water and the isinglass into a clean pan, and let them simmer over the fire for about an hour; add the rum when taken off the fire, then let it cool. Clean the glass, pour on the liquid, gild with camel's-hair tip, set the glass upon its

edge; the liquid will run from beneath the gold, and in less than 20 minutes you will have a burnished plate. When dry, rub lightly with fine cotton; if there are any spots not gilded, gild them. Draw your design on paper, perforate your lines with a needle, put your paper next the gilded side, with the reading the wrong way, dust through the holes with a rag and whiting, lift off the paper, and you will find your design marked off. If you wish the letters left clear black, cut round the letters with yellow, paint all over but the letters, wash off the gold with water, then paint all over black. If you want the letters gold, paint the letters yellow, and wash off the surplus gold, then paint all over black.

(4) Prof. Schwarzenbach, of Berne, has recently devised the following method of gilding on glass:—Pure chloride of gold is dissolved in water. The solution is filtered and diluted until in 20 qt. water but 15 gr. gold are contained. It is then rendered alkaline by the addition of soda. In order to reduce the gold chloride, alcohol, saturated with marsh gas and diluted with its own volume of water, is used. The reaction which ensues results in the deposition of metallic gold and the neutralization of the hydrochloric acid by the soda. In practice, to gild a plate of glass, the object is first cleaned, and placed above a second plate slightly larger, a space of about $\frac{1}{10}$ in. separating the two. Into this space the alkaline solution is poured, the reducing agent being added immediately before use. After 2 or 3 hours' repose, the gilding is solidly fixed, when the plate may be removed and washed.

Ornamenting.—Some ornamental processes during manufacture are:—(1) Upon the surface of a vessel in course of manufacture, small drops or seals of molten coloured glass may be fixed, and may be pressed by moulds into the form of stars, gems, &c. (2) A small quantity of molten glass is gathered upon the end of a working-rod, and allowed to lengthen by the force of gravity; the free end is attached to some point on the body of a vessel in course of manufacture, and the vessel is rapidly rotated; thus a thread is evenly coiled around the vessel. A machine is now being used for causing the vessel attached to the blow-pipe to revolve more evenly and rapidly than can be effected by the unaided skill of the workman. (3) If, after the first gathering, the bulb of white glass be dipped into a crucible containing coloured glass, a vessel may be formed with a coloured casing. In preparing coloured glasses for casing, great care must be taken that they shall neither be harder nor softer than the white metal, or the vessel formed is sure to crack. (4) If a bulb of molten glass be rolled upon variously coloured powdered glasses, flakes of mica, or leaves of gold, silver, or platinum, it will adhere to them, and, by continuous rolling, will amalgamate with them. Very beautiful effects of colour may be obtained in vessels made from glass prepared as described. (5) Iridescence, which is due to inequality of surface, may be produced by the action of an acid, or of the fumes of chloride of tin, upon the surface of glass. The glass, whilst hot, is subjected to the fumes of chloride of tin during manufacture. Any acid process must take place after the glass is annealed and cold. To effect iridescence, weak solutions of hydrofluoric or hydrochloric acids may be used. In the latter case, the process takes place in heated air-tight vessels. (6) Glass vessels may be frosted by plunging them, whilst still red-hot, into cold water, and afterwards reheating them. (7) Etchings in gold-leaf may be introduced into the substance of a vessel in the following manner:—The gold-leaf is floated on to a thin plate of glass, and etched. The plate of glass is heated, and a mass of molten glass is dropped upon the surface of the gold-leaf, and adheres to the thin plate of glass through the pores in the gold. The molten mass may be fashioned in the glass-house, or by the cutter. (Powell.)

If glass be left in a strong alkaline solution for some months, the surface

becomes so eroded that it gives by reflected light the colours of the spectrum in the most brilliant manner. This effect can be produced by ruling very fine lines upon glass plates, but those who have the patience to wait for 3 or 4 months while the glass is in its bath will be highly pleased with the result, and there is no patent on the process, because it is the outcome of an attempt to explain the iridescence found on articles of glass which have been buried for many centuries in moist earth. As to the solution, strong hyposulphite of soda will do, but probably the effects might be more rapidly produced by means of caustic potash or soda; but inferentially any strongly alkaline solution will answer. The common kinds of glass are more readily attacked than the hard varieties; but for ornamenting the ordinary blown water bottles and cast tumblers, basins, and jugs, no process can equal the iridescent. The only drawback is the time. (Mayer.)

Bay's Process for making the new kind of Glass which is smooth on one side and rough on the other (*Craquelé Indien.*)—The roughened surface of the glass looks as if it was covered with cracks, and this appearance is obtained by spreading over the surface of a plate of glass a thick layer of some flux or easily fusible glass that has been made fluid or pasty and mixed with coarser pieces. The glass is then put in a muffle or an open furnace and strongly heated. As soon as this flux is melted, and the glass itself becomes red-hot, it is taken out of the furnace and rapidly cooled. This flux or fused glass then cracks off from the other glass which was attacked by it, leaving numerous depressions in the latter, resembling scales and irregular crystalline forms, crossing and intersecting each other, and producing very beautiful effects when the light falls upon it. This fusible layer is cooled as rapidly as possible, either by a current of cold air or by carefully sprinkling with cold water. If some portions of the glass are protected from the action of the flux, the surface remains smooth there, in striking contrast to the crackled portion. This can be utilized in making arabesque letters, and other designs on a white or coloured ground. A similar crackled glass is made in another way, by strewing a coarsely-grained flux on a cylinder of glass while still red-hot, and then putting it back in the heating furnace until the flux melts. It is then rapidly cooled, either by sprinkling water on it or waving it back and forth. The layer of melted flux then cracks off and exposes the surface of the glass which has been corroded by it. The cylinder is then cut and spread out in the usual manner.

Fenrath has examined a "muslin" glass from Pivout, Charleroi. The enamel was very regular and homogeneous, and the surface could be readily cleaned; weak acids had no action on the enamel; concentrated nitric acid produced no change in 3 days; sulphide of ammonium, however, gave a greyish tint, whilst liquid hydrofluoric acid showed that the enamel was only incorporated on the surface of the glass. The substance giving the "matt" was very fine and delicate, and of a white tint, with a brownish-yellow shade; dilute acids dissolved out lead oxide and boric acid; hot water had no action on it. Its composition was—

Silica	42·99
Boron trioxide	6·25
Carbonic acid	trace
Stannic oxide	7·01
Lead oxide	37·78
Ferric oxide	0·11
Alumina	0·07
Potash	2·95
Soda (by difference)	2·84
	100·00

which represents a mixture of the following ingredients:—

Sand	100
Litharge	110
Crystal	110
Anhydrous borax	25
Potash stannate	25

(*Ding. Pol. Jl.*)

Three processes connected with the ornamentation of glass, porcelain, and

earthenware, were lately brought before the Société d'Encouragement, Paris. Cacault, of Colombes, prints, on the fine and hard earthenware of Breil, photographic impressions, which are fixed at a single burning. Lacroix, Paris, has produced pencils like those of graphite, but consisting of various vitrifiable colours. A design executed with them on glass, having the surface slightly dulled, stands the fire, and becomes fixed, like a painting on glass. A similar process, tried on porcelain a few years ago, is said not to have been successful. Lutz-Knechtle, a Swiss, decorates glass, cold, by his composition, made of a solution of silicate of soda or potassium, with the addition of zinc-white or ultramarine. The colours are applied by means of a stamp or roller, dry quickly, and stand washing. The surface of the glass is first finely ground, and any design is then painted on it with a mixture of anhydrous boracic acid, gum, and water. When dry, it is exposed to a temperature at which the boracic acid fuses, and imparts to those portions of the glass the usual lustre, and thus fixes the drawing. By mixing various metallic oxides with the boracic acid, designs in colour may be produced. (Dodé.)

The surface to be ornamented is covered with a sensitive varnish, and the design, being made transparent, is laid on the varnish, and the light is allowed to act on the sensitive film through the picture. After sufficient exposure, the picture is removed, and colours are applied in the following manner:—The finely-pulverized pigments or enamels are taken up (in a dry state) by a brush applied to the parts where they are required, which can be clearly distinguished in the layer of varnish on the article. The colours or enamels adhere more or less according to the degree to which the adhesiveness of the varnish has been affected; that is to say, according to lights and shades in the design to be reproduced, or according to whether the varnish has hardened more or less. The varnish may be composed of yellow gelatine, gum-tragacanth, and quince-seeds mixed with rain-water, and chrome salts, such as potash bichromate, added, to sensitize it. The composition of the varnish for normal conditions may be—

Filtered water . . .	500 parts
Gelatine	1 „
Gum-tragacanth . . .	10 „
Quince-seeds	3 „
Chrome salt (in crystals)	40 „

If the atmosphere is very dry, the quince-seeds may be replaced by sugar, glucose, or honey; or these may be used in addition. The proportions are merely approximate, as the exact preparation will have to be varied according to the conditions of the light, the degree of dryness of the air, and other conditions; but practice will readily suggest what is requisite to those skilled in kindred processes. When the oxides have been applied, they are protected by a coat of thick turpentine, such as is known in France as *terebenthine grasse*, attenuated, if required, by common turpentine, and the other superfluous parts of the varnish removed by immersion for 24 hours (more or less) in water acidulated with vinegar or other acid, say pure acetic or hydrochloric. The strength of the bath (viz. the proportion of acid therein) may be varied within reasonable limits, and determines the length of time which the immersion has to last. The more acid in the bath, the shorter the immersion; the weaker the bath, the longer the immersion has to be. The object is then dried, touched up, and further coloured with metallic oxides, if desired, and fired in a kiln. Copies of works of art and the like, such as portraits on glass (whether seen by transparency or by reflection), and either fired or not, whether they are drawn from nature or a copy of photographs, or of other design, are with advantage produced by making 2 or more *fac-simile* copies as above described, the copies being exactly fitted one over the other; 2 copies, whereof one at least is transparent, are sufficient in most cases. Upon one of these, the enamels, metallic oxides, or other suitable colours, may be applied, or it may be touched up after the colours are

fired; the second copy is placed over the coloured one, so that all details and contours register exactly in both pictures, and consequently appear as a single image to the eye. The 2 copies are united, especially, if on glass, fired with a flux applied at the edges, so that the 2, being fused together, form a single piece; this may also, when practicable, be effected by the firing which fixes the colours. The manner of uniting the plates by the interposition and fusion of a flux is the one which is preferable. Where a simple ornamental design, or ornamented surface without figures, is desired, it can be obtained upon glass and other articles by applying a varnish composed of asphaltum, pitch, or an equivalent material, dissolved in spirits of turpentine, to which sulphuric ether is added. The plate is then dried, and the design is applied; the plate is next treated with fluoric acid and water, mixed in suitable proportions, then washed in water, and the varnish is removed, as will be readily understood. This manner of proceeding produces plates which have a "frosted" or "crackled" appearance; that is to say, they appear as if covered by numerous vein-like grooves or marks. The varnish for this purpose may consist of—

Asphaltum	100 parts
Spirits of turpentine. .	50 ,,
Sulphuric ether . . .	50 ,,

These proportions may vary considerably, and according to their variation will produce a different design. The sulphuric ether may be replaced by light naphtha or by benzoline. The component parts of the varnish do not enter into chemical combination, but merely become mechanically mixed. The mixture is applied to the article by means of a brush or a pad, similarly to "stippling." By this means, the non-volatile fatty component parts of the varnish adhere in flakes or patches to the article, and protect it, and the fluoric acid attacks only the parts not so protected, and thereby the design is produced. (Micciullo.)

The exceedingly delicate coloured photographs on glass, which have come into fashion somewhat of late, are produced by fixing a paper photograph upon a cushion-shaped glass with transparent cement, and when it is dry, rubbing away two-thirds of the thickness of the photograph by sandpaper. The thin film left is then rendered transparent by soaking in melted paraffin wax, after which transparent colours are applied, which appear softened down when looked at from the front. The background and heavier portions of the picture are then painted in body colour upon the face of another cushion-shaped piece of glass, which is afterwards fixed behind the first one. An improvement in this process has just been made by Mrs. Nelson Decker, daughter of the late C. F. Varley, F.R.S. She has discovered that the second sheet of glass may be abolished, a better artistic effect be produced, and the picture rendered more permanent, by protecting it from the action of the air and deleterious gases by wholly embedding in paraffin. She does this by quickly dipping the photograph into paraffin a second time after the transparent colours have been applied, and painting the heavier colours upon the back of this second coat. A third layer of paraffin is then applied, and the background is painted upon that; this third coat may be finally protected by yet another layer of paraffin. Some practice is necessary to acquire the "knack" of doing this efficiently. It must be done rapidly enough not to re-melt previous layers, and the plate must, after each dipping, be quickly tilted on end in such a manner that the paraffin does not run into ridges and thickened lines, but forms an even coating. (*Engineer.*)

Protecting.—(1) In chemical laboratories it is customary to put a coating of clay on glass vessels that are to be exposed to a temperature that would soften or melt the glass, or where they are liable to be broken by draughts of air. Sometimes cows' hair or asbestos is mixed with the clay to strengthen it. Although this mass is cheap, it is liable to fine checks and cracks, or it scales

off, which frequently causes the glass to break. The disadvantages referred to can be entirely overcome by mixing up the materials with a little glycerine. This cheaply and easily prepared mass is thus rendered very easy to apply, always retains its desired softness, and never cracks nor checks. (*Gewerbeblatt.*)

(2) I have recently been using, with better results, a mixture of infusorial earth and water-glass, which, if properly applied, will last for weeks, and hence is not expensive, while it protects and strengthens the vessel to such an extent that I have, for the sake of experiment, heated thick but cracked retorts that were protected in this way to 400° or 500° C. (932° F.) when exhausted almost to a vacuum, and yet they did not break or collapse. It is important to make this mixture so that it shall form a soft and somewhat elastic, but not liquid, paste. A mixture of 1 part by weight of infusorial earth with 4 or 4½ of water-glass will fulfil this end approximately; the exact proportions cannot be given, because commercial water-glass differs in strength, and the infusorial silica is not always dry. The part of the vessel to be protected is covered ⅛ to ⅜ in. thick, and dried at not too high a temperature; it is better to dry in a drying closet or on a support over the stove. If the temperature is too high at first, it will cause air bubbles in the mass, and it is not so good then. It can be dried by swinging it back and forth over a flame, the bubbles being prevented by pressing them out. If a crack appears, it is plastered over with more of the mixture, and allowed to dry again. If some parts of the vessel are to remain transparent, they may be protected by water-glass alone, by applying several thin coats, and letting each dry before putting on the next. The same mass can be used to cover gas retorts, furnaces, stoves, and walls, just as well as for glass and porcelain utensils. (Schaal.)

Roughening.—This may be produced by the recently-invented sand-blast process, based upon the principle that if a stream of sand be made to fall through a vertical tube open to the air at the top, and the falling sand and air be received in a suitable closed vessel below, a jet or current of compressed air can be obtained. The entire surface of a vessel may thus be roughened, or, if parts are protected by a suitable medium, only the exposed portions will be abraded. By this means, very delicate patterns may be produced. Glass may be etched by the action of hydrofluoric acid, either in solution or in the form of gas. The variety in depth of incision, which gives the chief beauty to engraved glass, cannot be gained by either of these processes.

Spun.—To make fine glass thread, the glass is brought to a state of fusion, a glass rod is dipped in it, and thus a thread is pulled out, which solidifies first in its thinnest parts, and so causes a uniform thickness to be obtained. If this thread is placed over a hot metallic cylinder, and the latter is revolved, any length of thread may be obtained, and finer by revolving the cylinder more rapidly. The heating of the cylinder has the effect of annealing the glass to some extent, while the rapid cooling, if wound on a cold cylinder, would make it more brittle. A bundle of such threads looks like a bunch of silk, and it has therefore been called glass silk. It is largely used for filtering liquids in laboratories. In the microscope, the threads are as fine as those of silk or fibrillæ of cotton; they break more easily than the latter, but are excessively supple. From the unalterability of the substance, it is very well suited for filtering acid or alkaline solutions, even concentrated, and various other substances, such as nitrate of silver, albumen, collodion, Fehling's liquor, &c. It affords great rapidity of flow, with good filtration; it does not, like filters of paper or tissue, communicate organic matters to the liquids, altering and perhaps giving them a disagreeable taste. It is much preferable to asbestos, which, from the arrangement of its parallel fibres, cannot be formed into a flexible ball, and which lets frag-

ments pass that float in the liquid. For analysis it is very advantageous, allowing of a ready determination of insoluble matters deposited; also by calcination and fusion of the glass may be found the volatile principles fixed in the passage of the liquid, unmixed with empyreumatic products. Notwithstanding the price of glass silk is still high, it is no great expense to use it, as its excessive lightness admits of a considerable number of filtrations being made with a small weight of it; besides, it may serve an indefinite time, if after each operation, it is thoroughly washed with water and dried in the air.

Stoppering.—In stoppering a bottle, there are 2 processes: (1) The mouth of the bottle is opened to the required size by a steel cone revolving in a lathe; (2) the stopper is fixed in a wooden chuck, reduced to proper dimensions, and finally ground into the mouth of the bottle.

Writing on.—(1) Ether, 500 gr.; sandarac, 30 gr.; mastic, 30 gr. Dissolve, then add benzine in small quantities, till the varnish, spread on a piece of glass, gives it the aspect of roughened glass. The varnish is used cold. To have a homogeneous layer, pour over that already formed some oil of petroleum, let it evaporate a little, then rub in all directions with cambric cloth till all is quite dry. With ink or lead pencil, lines can be produced on this surface as fine as may be desired. Thus a drawing may be prepared in a few minutes and immediately projected. (Crova.)

(2) The glass is to be first gently heated at a spirit lamp or gas flame, till steam ceases to be deposited on it, up to 112° or 140° F. (44° to 60° C.). Then a particular varnish should be poured upon it, as is done in photographic operations with collodion. This varnish is composed of 51 dwt. alcohol, 61 gr. mastic in drops, and 122 gr. pounce. The resins are dissolved by being heated in a hot water bath, the whole being in a flask corked and fastened. The solution is afterwards filtered. The varnish is very hard, and becomes brilliant and completely transparent. If it is poured on the cold glass, it becomes opaque and absorbs ink. Drawings may be executed upon it with common or Indian ink. Then a thin layer of gum is put upon it by dipping the glass in a very diluted solution of gum or any other non-alcoholic coating. This process might be advantageously employed instead of labels on bottles in laboratories, and for making figures on glass, and perhaps for tracing drawings, which might thus be reproduced by photography. (Terquem.)

(3) A mixture of flour, ammonia hydrate, and hydrochloric acid, thickened with gum acacia, forms an ink by which, with a pen, letters or ornaments may be traced on glass, where they will become permanent.

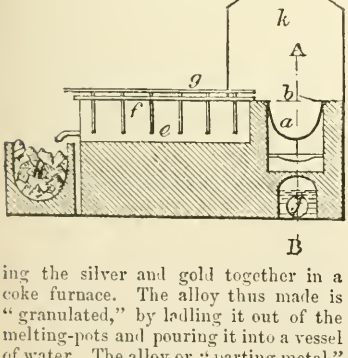
(4) Faber makes pencils for writing upon glass, porcelain, metal, &c., as follows:—*Black:* 10 parts lampblack, 40 white wax, 10 of tallow. *White:* 40 white-lead, 20 wax, 10 tallow. *Blue:* 10 Berlin blue, 20 wax, 10 tallow. *Dark Blue:* 15 Berlin blue, 5 gum-arabic, 10 tallow. *Yellow;* 10 chrome-yellow, 20 wax, 10 tallow.

GOLD.—Gold is one of the most widely distributed metals, and occurs almost always in the native state under 3 separate conditions—(1) as free gold in ancient and modern alluvial deposits; (2) encased in non-metalliferous rocks, chiefly quartz; and (3) associated with the sulphides and arsenides of other metals, principally iron and copper, more rarely lead and antimony. These 3 conditions of occurrence determine the mode of extraction. In the case of (1), advantage is taken of the great sp. gr. of the metal to separate it by more or less complicated washing processes in water; in the case of (2), the rock requires to be crushed to a gritty or even pulpy consistence before the washing operation can be entered upon; while in the case of (3), both the crushing and washing are brought into requisition in order to liberate the gold-holding part of the mass of ore, and this comparatively small proportion of the whole is subjected to chemical or

metallurgical treatment for the purpose of isolating its metallic contents, with which the gold is associated. This last-mentioned treatment varies with the nature of the metalliferous mass, and will be found described under the heads of the various other metals concerned. When the gold is by these means rendered independent of its former associated baser metals, it is in a condition which admits of its recovery by agitating the mass with mercury, which has a great affinity for gold, and rapidly forms an amalgam with it. The mercury is then distilled off for re-use, and the gold thus obtained is sent into the market. It always contains more or less silver, and has to be subjected to an operation known as "parting," which, however, is only done in the refinery where the metal is worked up. The proportion of silver present is ascertained by assay, and governs the market price per oz. of the commercial metal.

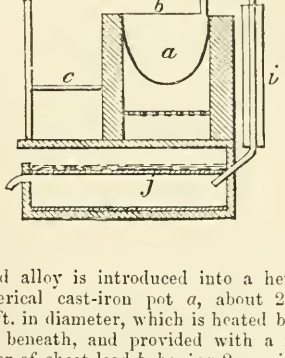
Refining.—The object sought is the removal from the gold of every particle of foreign metals, such as silver, copper, lead, antimony, which may be present. The process depends upon the solubility of these metals in certain hot acids which have no solvent action upon gold. When the operation is conducted on a large scale, with plenty of space for the requisite plant, concentrated sulphuric acid (oil of vitriol) is the acid employed; but under other conditions nitric acid is used. At some establishments, both the sulphuric acid and the nitric acid processes are used, according to circumcumstances, but generally only one or the other of them. Neither of these acids, however, will by any length of boiling remove from the gold the silver which it contains in small proportion; to enable the acid to dissolve it, the proportion of silver has to be greatly increased. The first thing, therefore, done with the gold is to alloy it with 3 times its weight of silver, which contains a limited proportion of copper. This process is technically termed "quartation," and is effected by melting the silver and gold together in a coke furnace. The alloy thus made is "granulated," by ladling it out of the melting-pots and pouring it into a vessel of water. The alloy or "parting metal" is then in a physical condition favourable for the action of the acid upon it. The acid portion of the operation is technically termed "parting."

Fig. 130.



B

Fig. 131.



When sulphuric acid is used as the solvent, the plant employed is that represented in Figs. 130, 131. The granulated alloy is introduced into a hemispherical cast-iron pot *a*, about 2 or 2½ ft. in diameter, which is heated by a fire beneath, and provided with a flat cover of sheet-lead *b*, having 2 openings near its front part (the side nearest the workman's platform *c*). The smaller of these openings, provided for the introduction of a siphon, has usually a removable cover; the other, a larger opening used for the introduction of the materials, is usually furnished with a

hinged cover. There is also, proceeding from the back part of the leaden covering, a pipe *d*, made either of lead or platinum, the use of which is to convey away the vapours generated in the process. The alloy having been thrown in, oil of vitriol is added in some excess of the quantity known to be requisite for the solution of the metals in the alloy, and heat is applied. The sulphuric acid is heated to boiling, and after about 1 hour's heating, the solution is usually complete, the foreign metals are dissolved, and the gold lies at the bottom of the pot in a powdery condition. The reaction which takes place is this: half the sulphuric acid necessary for the solution of the metals is decomposed, giving 1 of its 3 atoms of oxygen to them for their oxidation, thus reducing this proportion of the acid to the condition of sulphurous acid, which is evolved in the gaseous state; the other half of the acid necessary for the solution combines with the metallic oxides thus formed to produce silver, copper, lead, &c., sulphates. The acid used being in excess, the liquor is still acid. Abundant and dense white acid fumes are evolved; they consist of steam, sulphuric acid vapour, and sulphurous acid. When the solution is complete, and the gold has subsided to the bottom of the iron pot, the liquor is ladled, or, by means of a platinum siphon, drawn off into water contained in a lead-lined tank *e*, which is furnished with a wooden cover *f*, in some works completely, and at other works imperfectly. In the former case, a hole in the cover is provided, through which the long arm of the siphon is introduced. The temperature is now raised by the injection of steam through the pipes *g*. In this tank the diluted solution remains for about 3 hours. Being left to rest for a time, a deposit of lead sulphate, &c., occurs, and then the clear solution is drawn off by a tap near the bottom into another vessel or tank *h*, lined with lead, and containing sheets of copper; this tank is uncovered. The liquor, as it runs from the tank *e*, is of a blue colour, due to the copper sulphate it contains. The object of the copper is to decompose the silver sulphate in solution. the result of the action being the solution of the copper with the formation of copper sulphate, and the deposition of the silver of the silver sulphate in a powdery condition. The solution of copper sulphate is run off into appropriate tanks, and the silver, being removed, washed with water, and pressed in a hydraulic press, is melted into ingots of pure silver. The gold taken out of the iron pot is not, however, even now absolutely free from silver. Hence, to remove the last traces of this metal, the gold in the powdery condition is boiled again in a smaller pot with more oil of vitriol, the heating being continued for 2 hours. At small works, this boiling is effected in the same pot as the first boiling. The gold is then washed with hot rain or distilled water, fused with soda bicarbonate in a graphite crucible, and subsequently melted into ingots. The solution of copper sulphate has now to be dealt with. It is therefore transferred to a lead-lined tank, heated by a fire beneath, where it is evaporated down, and from which it is transferred into cooling-vats to crystallize. The crude salt is again dissolved and recrystallized to prepare it for sale. The rooms in which all these operations are conducted are usually lofty and capacious, and ventilated by louvres at the roof.

In the nitric acid method, the granulated alloy is introduced into a platinum vessel of cylindrical form, like a show tea-canister, and 18 to 24 in. high, with a wide, short-necked opening at the top, into which a stoneware pipe can be fitted to carry off the fumes generated in the process, and another opening fitted with a cover, by means of which the solution is at the end of the operation poured off. At some works, the platinum vessel is provided with a short spout, through which the solution is poured out, and the vessel itself is furnished with pivots at the sides, which work upon iron supports, so that it may be tilted up to empty the liquid matters.

The gold alloy having been introduced and the nitric acid added, heat is applied below, either by a coke fire or by the flame of gas. At works in Sheffield where the nitric acid parting is performed on a small scale, large glass flasks, heated each upon a separate sand-bath, are used instead of platinum vessels. The operation of solution of the foreign metals occupies about 6 hours, during which time acid fumes are being given off. Part of the nitric acid is decomposed to oxidize the metals, with evolution of nitrous fumes, part unites with the oxides to form nitrates, and part comes off with watery vapour as nitric acid. Acid fumes are given out during the whole process of solution; but the nitrous fumes are most abundant in the earlier part of the process, and nitric acid fumes at the latter part. Acid fumes also rise when the contents of the platinum or glass vessel are poured out. The solution of the nitrates of silver, &c., poured from the platinum vessel or glass flask, is submitted to the decomposing action of copper in appropriate wooden vessels, and the solution of copper nitrate produced is reduced by iron or is sold to chemical manufacturers who may require it; or the impure silver solution is evaporated down, and crystallized and recrystallized so as to obtain silver nitrate in a sufficiently pure state for sale.

It is quite practicable to obviate nuisance, whichever process of "parting" may be in use. As respects the sulphuric acid process, the more essential requisites for the attainment of this object are efficient means of drawing off the vapours from the pot and the tank *d*, and proper means of disposing of them when drawn off. The draught of the chimney of the works may be used as the agent for the aspiration, or a jet of steam may be thrown into some convenient part of the pipe which conducts the vapours away, or the chimney draught may be aided by the steam jet. But the adaptability of the steam jet will in part depend upon the method of condensing the vapour which is preferred at the individual establishment. At Rothschild's and at Raphael's refineries, the acid vapour is condensed by means of cold, the object being to recover the evolved sulphuric acid as little dilute as possible. The method adopted is virtually the same at these two establishments. The arrangements for the first part of the condensation at Raphael's works are represented in Fig. 131. The pipe *d* is bent downwards towards the floor of the works, and in this vertical part is jacketed, cold water flowing through the jacket *i*. This pipe terminates below in a leaden pipe *j*, about 16 in. wide and 20 ft. long, which lies horizontally in a trough of cold water. From this pipe any uncondensed fume passes into a leaden chamber, 10 ft. long, 4 ft. wide, and 5 ft. high, having 8 curtains arranged within it, so that the fume must pass alternately up and down in the chamber while traversing it from one end to the other. It is now conducted by a long pipe arranged round the interior of the workroom to a series of 3 leaden scrubbers, each about 6 ft. high by 3 ft. wide, and filled with large coke, which scrubbers the fume enters alternately at the bottom and the top, and, from the last of which, uncondensed gases pass away to a chimney 145 ft. high. At Rothschild's works there are no fewer than 12 leaden chambers distributed about the works, and in the cellars, as room could be found for them, each 6 ft. square; the fume has to pass through the whole series, and finally through 3 coke scrubbers similar to those in use at Raphael's works, on its way to the chimney, which is about 200 ft. high. The acid collected in the various parts of these condensing arrangements is strong enough to make it worth while to concentrate it for use again in the iron pot (or about 60° Beaumé). The concentration is effected at both the works mentioned by means of a cast-iron still with a leaden or platinum lining, and it is with a view to economy of acid and the utilization of the acid saved that the method of condensation described has been adopted. The sulphurous acid gas which passes into the chimney

is discharged at too great an elevation to be any nuisance. At Rothschild's works, the tank *c* is closely covered down, and a pipe conveys the acid fume drawn off from it first through a condensing pipe surrounded with cold water, and then into the leaden chambers; it is in fact dealt with first in the same way as the fumes from the iron pot. In another establishment, the acid fumes from the pot, drawn off by means of a steam jet, are driven into a lead-lined covered tank filled with cold water, which effectually arrests the sulphuric acid; the uncondensed gases pass off from the tank into the chimney of the works. In another case, the acid fume, first passed through a leaden pipe immersed in a trough of cold running water, is conducted through a small leaden chamber or scrubber packed with coke kept constantly wet with water, the aspirating force being the chimney draught. At both these last-mentioned establishments a use is found for the dilute sulphuric acid thus obtained, and nuisance is quite avoided. Over-heating and too violent boiling in the iron pot may be avoided by duly careful working. The escape of acid during the removal of gold from the large to the small pot is avoidable by waiting until the large pot has sufficiently cooled down, and by taking care that the small pot is not much heated before the gold is transferred to it. Where the same pot is used for both boilings, the fire should be drawn ½ hour before the solution is ladled out and fresh sulphuric acid is added. At Rothschild's refinery, a provision against nuisance from the accidental evolution of acid fumes from the pot into the atmosphere of the workshop, is made by enclosing the part of the apparatus where the pot is situated within a leaden closet or hood *k*. It is glazed on one side for the admission of light, and is open on the side next the working platform. From the top a wide pipe conducts away fume which rises into it to one of the leaden condensing chambers already described.

It is to the advantage of the refiner to save as much as possible of the nitric acid evolved during the nitric acid process. At Johnson and Matthey's works this is effected by carrying the stoneware pipe attached to the mouth of the platinum vessel into a capacious stoneware jar, shaped like a chemist's Wolffe's bottle, and from this by long stoneware pipes placed vertically and rising to the roof of the chamber, and then bent downwards, to 2 other similar bottles. In these bottles the greater part of the acid condenses and is collected. So much of the nitrous acid as is not condensed with the nitric acid is conducted by a pipe proceeding from the last bottle to the back part of the ashpit of a coke fire, which is always in use and well kept up. Nuisance is thus avoided. (Dr. Ballard's Report.)

Rössler improves on the sulphuric acid process by allowing the sulphuric acid solution of silver to crystallize, with addition of a little water. The yellow crystals of silver sulphate are then put into water, and metallic iron is gradually added, by which all the silver is precipitated, but the copper remains in solution. The impurities introduced with the iron are removed in the slag on fusion, and the silver is purer than when the copper is deposited with it.

Coinage gold, not containing more than $\frac{1}{10}$ silver, is generally refined by Miller's chlorine process, which consists in melting the gold in a clay crucible glazed inside with borax, and passing chlorine gas through the liquid metal from a clay tube; the silver is attacked immediately by the chlorine, and rises to the surface as chloride, while the chlorides of other metals present (*e.g.* antimony, arsenic, bismuth, zinc) are volatilized, leaving the gold pure, except about 3 to 9 parts of silver per 1000. On the top of the fused mass in the crucible is put a layer of melted borax, which prevents volatilization of the silver chloride. Absolutely pure gold may be prepared by Rössler's process just described, or by the following method:—The alloy is dissolved in aqua-regia, and concentrated to drive off the

nitric acid; after diluting with water, and filtering, the metallic gold is precipitated by a reducing agent, ferrous sulphate ($FeSO_4$) being commonly employed. Another good reducing agent is oxalic acid; on adding a little oxalic acid and an excess of potassium carbonate to a gold solution, a clear solution is produced, which decomposes on further addition of oxalic acid, and precipitates the gold when quickly heated to boiling. The character of the gold varies with the mode of precipitation, thus:—(1) The gold is obtained in very fine powder when the gold solution is poured into the ferrous sulphate solution; (2) it is scaly and more lustrous when the ferrous sulphate is poured into the gold solution; (3) it forms a fine yellow spongy mass when precipitated by oxalic acid. It is rendered compact and coherent by fusion with borax and nitre.

The physical properties of gold render it one of the most useful metals. Whilst resisting the action of oxygen and of water at all temperatures, its divisibility is such that 1 gr. can be made to coat 2 miles of fine silver wire; and its extreme ductility and malleability are shown by the fact that 1 gr. can be hammered out to cover an area of $56\frac{3}{4}$ sq. in., or so that 280,000 leaves are required to make a thickness of 1 in.; and its wire can be drawn so fine that 1 gr. will make 700 ft. It is insoluble in all simple acids but selenic, and it suffers no change when fused with potash chlorate; but it is attacked by nitrates and alkalies, and dissolves readily in any acid liquid evolving chlorine (*e.g.* aqua-regia). Its sp. gr. is 19·265, and its fusing-point is placed by different authorities at 1898° to 2517° F. (1037° to 1381° C.).

The reader desiring more detailed information on "gold-mining" is referred to A. G. Lock's 'Gold: Its Occurrence and Extraction.'

INDIUM.—This metal occurs in very small proportions in some zinc-blendes. It is best prepared from metallic zinc from Freiberg, Saxony, which contains about $\frac{1}{10}$ per cent., in the following manner:—The zinc is almost completely dissolved in hydrochloric acid, and, after standing 2 or 3 days, the indium is precipitated on the zinc remaining undissolved. The indium powder is washed off the zinc, and a few drops of dilute sulphuric acid are added to dissolve any basic zinc chloride formed; the spongy metal is well washed with hot water and treated with nitric acid; the unfiltered acid solution is boiled with excess of sulphuric acid till all the nitric acid is driven off; the solution is filtered, the residue is well washed, and large excess of ammonia is added to the filtrate; the cadmium, copper, and zinc mostly remain in solution, while all the indium, iron, and lead are deposited; this latter residue is well washed, dissolved in a little hydrochloric acid, treated with excess of hydric-sodic sulphite, and boiled till sulphurous acid fumes cease; the precipitate formed is indium sulphite, which is purified by solution, and boiling in sulphurous acid; the pure salt decomposes when strongly heated, leaving a residue of indium oxide, which can be reduced to metal either by ignition in a current of hydrogen or by fusion with sodium. The latter plan is the better for dealing with any quantity, and is thus carried out:—The finely-divided oxide is packed in alternate layers with thin slices of sodium in a porcelain crucible, and covered with a thick coat of anhydrous sodium chloride; the porcelain crucible and its contents are put into a covered Hessian crucible, and gently heated till the reaction is complete, when the temperature is increased to moderate redness; the brittle alloy obtained is boiled several times in water, washed with alcohol and ether, and re-fused under potassium cyanide; the last traces of sodium are removed from the regulus by throwing it, in small pieces, into fused soda carbonate, when the indium is obtained pure. It is a malleable metal, softer than lead, of a white colour, and non-crystalline; it dissolves rapidly in nitric acid and slowly in hydrochloric and dilute sulphuric; it has a sp. gr. of 7·42, melts at 349° F. (176° C.), and retains its lustre even in boiling water.

IRIDIUM.—This valuable metal occurs pretty abundantly in platinum and osmium alloys, forming 27 to 77 per cent. of the mineral platiniridium, and 53½ to 58 per cent. of osmiridium. The preparation of pure iridium has been made a specialty by Johnson and Matthey, the well-known refiners and assayers, and is thus described by G. Matthey, F.R.S.:—

The metal is prepared with the object of being used in iridio-platinum alloy, consequently it is not necessary to free it from platinum, and the process is devoted only to the removal of all other impurities. In practice, the purest iridium which can be obtained from its ordinary solution (deprived of osmium by long boiling in aqua-regia, and precipitated by ammonium chloride), will almost invariably contain traces of platinum, rhodium, ruthenium, and iron. Such iridium, in a fine state of division, is fused with 10 times its weight of lead, keeping it in a molten state for some hours; the lead is dissolved out by nitric acid, and the residue is subjected to prolonged digestion in aqua-regia, yielding a crystalline mass composed of iridium, rhodium, ruthenium, and iron, in a condition suitable for further treatment. By fusion at a high temperature with an admixture of potash bisulphate, the rhodium is almost entirely removed, any remaining trace being taken up together with the iron in a later operation. The iridium, so far prepared, is melted, with 10 times its weight of dry caustic potash and 3 times its weight of nitre, in a gold pan or crucible, the process being prolonged for a considerable time to effect the complete transformation of the material into potash iridiate and ruthenate, as well as the oxidation of the iron; when cold, the mixture is treated with cold distilled water. The potash iridiate, of a blue tinge, will remain as a deposit almost insoluble in water, more especially if slightly alkaline; the iron oxide also remains. The precipitate is well washed with water charged with a little soda hypochlorite and potash till the washings are no longer coloured; then several times with distilled water. The blue powder is mixed with water strongly charged with soda hypochlorite, and allowed to remain for a time cold; then warmed in a distilling vessel, and finally brought to boiling-point until the distillate ceases to give a red colour to weak alcohol acidulated with hydrochloric acid. The residue is again heated with nitre and potash-water charged with soda hypochlorite and chlorine, until the last trace of ruthenium has disappeared. The blue powder (iridium oxide) is re-dissolved in aqua-regia, evaporated to dryness, re-dissolved in water, and filtered. The dark-coloured solution thus obtained is slowly poured into a concentrated solution of soda, and mixed with soda hypochlorite; it should remain as a clear solution without any perceptible precipitate, and, when subjected in a distilling apparatus to a stream of chlorine gas, should not show a trace of ruthenium when hydrochloric acid and alcohol are introduced into the receiver. In this operation the chlorine precipitates the greater part of the iridium in a state of blue oxide, which, after being collected, washed, and dried, is placed in a porcelain or glass tube, and subjected to the combined action of carbon oxide and carbonic acid, obtained by gently heating a mixture of oxalic and sulphuric acids. The iridium oxide is reduced by the action of the gas, leaving the iron oxide intact; the mass is then heated to redness with potash bisulphate (which will take up the iron and any remaining trace of rhodium), and after subjecting it to many washings with distilled water, the residue is washed with chlorine water to remove any trace of gold, and finally with hydrofluoric acid in order to take out any silica which might have been accidentally introduced with the alkalies employed, or have come off the vessels used. The iridium, after calcination at a strong heat in a charcoal crucible, is melted into an ingot; and after being broken up and boiled in hydrochloric acid, to remove any possible trace of iron adhering to it through the abrasion in breaking up,

should possess, if perfectly pure, a density of 22·39; but as iridium, prepared even with the utmost care, will still contain minute though almost inappreciable traces of oxygen, ruthenium, rhodium, and possibly iron, the highest density attained by Matthey was 22·38.

Deville et Debray's method of purifying unrefined iridium is as follows:—The metal is ignited with barium nitrate, and the mass is treated with water, when the residue consists of iridium oxide and barium osmate; this is boiled with nitric acid to remove the osmium, which volatilizes as tetroxide; the iridium oxide is precipitated from the residual solution by baryta, dissolved in aqua-regia, and then thrown down as iridio-ammonium chloride; on ignition, this yields spongy iridium, containing small quantities of platinum, ruthenium, and rhodium; ignited with potassium nitrate and treated with water, potassium ruthenate is dissolved; the residue, fused with lead, gives a regulus, which, treated with nitric acid and aqua-regia, affords the pure metal.

Compact iridium is oxidized when heated with acid potassium sulphate, or in presence of fused alkalies; when pure, it is not attacked by aqua-regia, but dissolves when alloyed with much platinum; it is slightly volatile, but extremely difficult of fusion; it has a sp. gr. of 22·38, and a colour resembling polished steel; it is very brittle when cold, but somewhat malleable at a white heat; when an alcoholic solution of the sulphate is exposed to sunlight, the metal is deposited as an impalpable powder, and the merest trace of this iridium-black, washed with hot water, dried, and thrown on paper saturated with alcohol, produces ignition, the metal being converted into grey sponge. The only important use to which the metal has been devoted is for the preparation of an alloy suitable for standard measures; this alloy, consisting of 1 part pure iridium and 9 platinum, is extremely hard, as elastic as steel, less fusible than platinum, perfectly unalterable in the air, and capable of taking a fine polish; some standard rules made by Johnson & Matthey gave the following composition: 89·41 platinum, 10·17 iridium, 0·17 rhodium, 0·10 rubidium, 0·06 iron.

IRON AND STEEL.—Without entering into the details of the manufacture of iron and steel, which would be out of place here, there are many matters relating to the subsequent modifications and applications of these metals not readily to be found in the general literature of the subject. These will receive attention.

Decorating. — (1) Bright steel surfaces may be ornamented with initials, a cipher, or a pattern, by the following process:—If the ornament is to be bright upon a dead ground, take a camel-hair pencil and draw with it upon the steel the letters or patterns in Brunswick black. If the ornament is to be dead upon a bright ground, the letters or patterns must be left untouched, and the whole of the ground painted over with the pigment. A little aquafortis (dilute nitric acid) is then poured upon the exposed parts of the steel, and in a few minutes it will be seen to have eaten sufficiently into the metal. When this is done, wash off the aquafortis with water, and remove the Brunswick black with turpentine. A pretty variety in steel decoration may be made by introducing blue ornaments. Steel may be rendered a beautiful blue by exposure to heat, and the blue colour can be removed, where it is not required in the pattern, with white wine vinegar or other weak acid, the parts to remain blue being protected as before with Brunswick black. On the parts from which the blue is removed, further variety may be gained by painting additional ornaments in Brunswick black, and exposing the remainder of the ground to the action of the aquafortis. If the parts which receive these latter ornaments are afterwards polished, the pattern will present 3 varieties, viz., bright blue, bright white, and dead white. Gilding on steel was formerly done with spirit; now, if the operator can conveniently send his work to an electro-gilder's, he

will find it well to do so, first painting over with Brunswick black those parts which are not to be gilt. Or the gilding may be performed at home by the following method:—If sulphuric ether and nitro-muriate of gold are mixed together, the ether will, by degrees, remove from the acid nearly the whole of the gold, and retain it for a long time in solution. Take ether thus charged, and with the camel-hair pencil paint over the parts of the design intended to be in gold; after giving the ether time to evaporate, rub over the parts thus gilt with a burnisher. After the completion of the design, the bright surface of the steel may be restored, in any place where it has become dim, by rubbing with a little whiting. (*Cassell's Household Guide.*)

(2) Damascening. — By damascened steel is meant that sort of steel which receives shades of darker and lighter colour after the surface has been corroded with acids: it is remarkable, when genuine, for its elasticity, strength, and homogeneous fracture when broken.

(*a*) Natural Damascus steel comes from India and Persia, is distinguished by its excellent quality and mixed veining, and is worked up principally into sword blades. These Oriental blades consist of a more highly carburetted steel than any European manufacture seems to possess, and in which, by skilful cooling, a division of 2 different carburets has taken place. This separation is clearly visible on corrosion with acids, as the parts subjected to the action of the acid are deepened and dyed by the exposure of the carbon, and, with the other less affected and consequently brighter parts, produce a design, more or less delicate, of grey and white lines, which often have a certain degree of regularity. A distinction is made between parallel striping or waving lines and mosaic damascening. If the cast-steel is made in iron moulds, as usual, the above separations do not take place. By re-welding and sudden cooling, the Damascus steel loses its pattern. The Indian Woolz, as especially used for sword-blades, contains foreign substances mixed with it—as nickel, tungstate of iron, or manganese—which are said to impart peculiar value. Few European smiths succeed in working up Indian steel, because they do not accurately know the temperature required for its treatment. In consequence of the large amount of carbon it contains (7·18 per cent.), this can only be effected within certain climatic limits: if too high a temperature is exhibited, it breaks to pieces under the hammer; if too low, it assumes a hard and brittle character. The iron appears disposed to receive a considerable quantity of carbon, through the manganese combination.

(*b*) Artificial damascened steel. Attempts have been made, with more or less success, to imitate the real damascening, and the following methods have been suggested:—

Luynes imitated the Indian process; smelting soft iron with charcoal, tungstate of iron, nickel, and manganese, was highly successful. The manganese, more especially, produced damascened steel, and introduced a large quantity of carbon without injuring its malleability.

Bréant produces a most valuable damask, very closely resembling the real, by smelting 100 parts iron with 2 of lampblack, or by smelting cast-iron with oxidized iron filings.

Clouet, Hachette, and Mille smelt iron plates of different natures, harder and softer, together, and produce a damask remarkable for its elasticity and hardness, but not having the wavy damascening of the real blades.

(3) Browning.—All browning methods known at present, obtained by moistening iron with acid, copper, or iron solutions, permitting them to dry in air, brushing off the rust formed in this manner, and repeating the operation several times, only produce a more or less light or dark red-brown rust coating upon iron articles. Baril's process, as well as that of heating iron articles in superheated aqueous vapour, only causes an iron protoxide layer upon iron.

These last-mentioned two methods have the further defect that the protoxide of iron layer peels off in a short time, whereby rust is invited. Iron articles are easily coppered or brassed by dipping in copper solutions, or coppered or brassed by the galvanic method; these coatings also scale off after a short time, especially if the iron surface was not thoroughly cleaned, when exposed to the influence of moist air.

By the following process, it is easy to provide iron articles with a handsome bronze-coloured protoxide coating; it resists the influence of humidity pretty well, and besides this, the operator has it in his power to produce any desired bronze colour in a simple manner. The cleansed and scoured articles are exposed to the vapours of a heated mixture of concentrated hydrochloric and nitric acids (1 and 1) for 2 to 5 minutes; and then, without unnecessarily touching them, heated to a temperature of 572° to 662° F. (300° to 350° C.). The heating is continued until the bronze colour becomes visible upon the articles. After they have been cooled, they are rubbed over with petroleum jelly, and again heated until the jelly begins to decompose. After cooling, the article is anew rubbed over with petroleum jelly. If now the vapours from a mixture of concentrated hydrochloric and nitric acids are permitted to operate upon the iron article, light red-brown tones are obtained. However, if acetic acid is mixed with the before-mentioned acids, and the vapours are permitted to operate upon the iron, oxide coatings are obtained possessing a handsome bronze-yellow colour. All gradations of colours from dark red-brown to light red-brown, or from light bronze-yellow to dark brown-yellow, are produced by varying the mixtures of the acids. T-rods, 4½ ft. long, for iron boxes, coated with such oxide layers, after 10 months, during which time they were continuously exposed to the influence of the air of a laboratory constantly laden with acid vapours, do not betray the slightest traces of change. (Prof. Oser, *Ding. Pol. Jl.*)

Malleable.—Malleable iron is iron which has been "decarburized" (deprived of its carbon) by the action of air upon it in a molten state. There are several ways of doing this.

(*a*) The "bloomery" process, necessitating the employment of wood charcoal, is conducted in a "finery," originally consisting of a rectangular shallow hearth, lined with 2-in. or 3-in. iron plates, protected by an inside coating of "brasque" (charcoal dust), with holes in the front plate for the exit of the slag. The "twyer" or blast-pipe (*tuyère*) is set at an angle of 5° to 16°, and the depth of the hearth is 6 to 10 in. When the furnace is heated and ready, layers of fuel and 2-in. or 3-in. lumps of iron are thrown on the hearth, and the blast is put on. As the molten metal reaches the bottom of the hearth, it encounters the blast from the twyer, "the result being that the silicon in the pig is more or less oxidized to silica, the carbon to carbonic acid, and the iron to oxide of iron. The oxide of iron combines with the silica, the liquid slag thus formed dissolves a further quantity of oxide, and being intimately mixed with the carbonized iron, re-acts upon it, removing the carbon." (Prof. Huntington.) Means are taken to thoroughly break up and expose the iron to the blast from the twyer, and when the operation is judged to be complete, the metal is withdrawn as a spongy "ball" laden with slag; while still white hot, it is squeezed under a hammer to expel the slag, and welded into a rectangular "bloom," or slab, which is afterwards reheated and drawn out into a bar. The expressed slag contains 70 to 80 per cent. of iron protoxide, and is returned to the hearth with subsequent charges to help in removing their carbon. The best iron for the purpose is white pig, as it becomes pasty in melting.

Fig. 132 shows a furnace described by Dalifol, adapted for using wood charcoal: *a*, 4 conduits for admitting air into the furnace; *b*, openings for charging in the charcoal; *c*, 2 little plates for preventing the sides of the furnaces

from meeting when bent by the heat; *d*, tie bars.

(*b*) When grey pig-iron is used for making malleable iron, it must first be converted into white iron by the "whitening" process in a "refinery," which also removes most of the silicon. Fig. 133 shows a modern "refinery" as

Fig. 132.

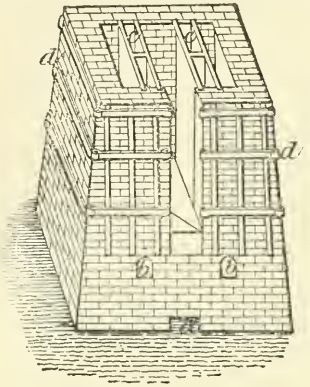
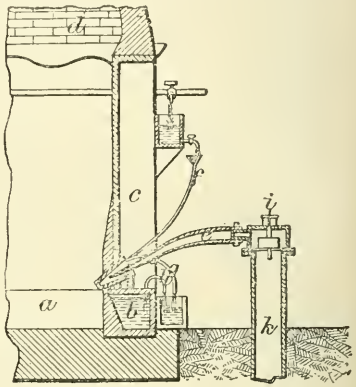


Fig. 133.



described by Prof. Huntington. It consists of an oblong hearth *a*, 3 ft. long, 2 ft. wide, 2½ ft. deep (on which the fuel and pig-iron are placed), surrounded on 3 sides by iron blocks *b*, cooled by water, and on the fourth (in front) by a solid cast-iron plate with a tap-hole at the bottom; *c* are hollow iron columns for supporting the chimney *d*, about 18 ft. high; *e*, twyers placed at an inclination of 25° to 30°; *f*, funnel pipes for supplying cold water to the twyers; *g*, overflow pipes for taking away the heated water from the twyers; *h*, similar pipes for performing the same service to the channels *b*; *i*, valves for regulating the blast furnished by the pipes *k*, which is usually about 400 cub. ft. per minute at a pressure of 1½ to 3 lb. per sq. in. The hearth is supplied with alternate layers of fuel (generally coke) and pig-iron, commencing and finishing with the former. The charge is subjected to the blast for about 2 hours, the first 1½ hours being required to effect the melting. The cinder and "fine" or "plate" metal are tapped into a shallow cast-iron loam-lined mould, cooled by circulating water, whereby the metal is cast into a plate 10 ft. long, 3 ft. wide, and 2 in. thick, while most of the slag escapes to a second mould beyond, and the residue can be easily removed from the cool surface of the plate. The metal is further chilled by having water thrown on it, and can then be broken up readily; it should have a bright fracture and show no honeycomb.

(*c*) Puddling.— Where supplies of wood for making charcoal are scarce, the "puddling" process is in vogue. Many forms of furnace are employed, but the main feature underlying them all is that the fuel (coal or coke) is burnt in a separate chamber, so that the heated gases only reach the metal, whereby the sulphur present is oxidized and rendered harmless before arriving at the metal. In general terms, the furnace consists of a fireplace, a hearth, and a flue leading to a chimney, bridges separating the hearth from the fireplace and flue respectively. The form and size of the hearth are governed by the character of the fuel, which is preferably dry, non-caking, and burns with a long flame. The floor of the hearth is

made of 1¼-in. cast-iron plates, and covered with a layer of materials rich in iron oxide, such as slag and bloom scale, strongly heated, and spread about 2 in. thick. The "fettling" or lining, known as "bulldog," is obtained by roasting "tap cinder" (the slag of the puddling furnace), which is essentially a silicate of protoxide of iron, till the protoxide is converted into peroxide, and the silica is liberated. This is smoothed over with "puddlers' mine," which is a soft hematite made into a paste with water.

The puddling operation is performed with a "rabble" or a "paddle," and by 2 methods, known as "dry puddling" and "pig-boiling." The former method requires white iron, wastes less metal, and consumes less fuel; but the sulphur and phosphorus are not so well removed. In the latter method, grey iron is used. The details of puddling furnaces are too diffuse and complicated for further discussion here. (See Spons' *Dictionary*, article "Iron.")

(*d*) The *Chemische Centralblatt* describes the following method practised in Germany for the preparation of malleable cast-iron:—It consists of two operations: (1) pouring the cast-iron into moulds, and (2) removing part of the carbon contained in the castings. This is conducted in so-called "temporary" furnaces, wherein the castings are brought into contact with substances containing oxygen and heated to redness. The result is the formation of a very tough material, poor in carbon. The castings, contained in cast-iron vessels, are placed on a layer of oxidizing substances, and the intervening spaces are filled up with the latter. Oxide of zinc, hammer scale, brown and red iron ores, are used for this purpose—mostly the latter. The operation lasts 24 to 36 hours, and depends on the dimensions of the iron to be tempered and the degree of tempering. With regard to the latter, the limits are within a wide range, as, with a correct formula for mixing, it is possible to absorb the whole of the carbon. It is best to use iron free from manganese and containing amorphous carbon—that is, white pig-iron. The tempered iron forms an excellent material, and compares favourably with malleable iron as to firmness. It can be worked and polished with file and chisel, or forged and welded at a moderate red heat.

(*e*) Malleable-iron Castings.—The term malleable-iron castings means an iron that has been cast into any desired shape, and then malleableized by removing the carbon by a process of annealing, which consists in burning off the whole or a part of the carbon combined with the iron from which the castings were made. In the manufacture of malleable-iron castings, the first object is to get the proper kind of pig-iron, for all iron is not suitable for making malleable iron by the process of annealing. From the states in which carbon exists in cast-iron, this has been classified into 3 principal subdivisions. The first is "grey" metal, or "No. 1 foundry pig," in which the carbon is not combined with the iron, but is in the graphitic state, and may be seen in large flakes when the iron is broken. These flakes are sometimes called "tissue" and "black-lead." The second division is "mottled" cast-iron. In this the carbon is partly combined with iron and partly in the graphitic state, which gives the iron a spotted or mottled appearance. The third division is "white" cast-iron. In this the carbon is combined with the iron, and is unseen.

Grey or No. 1 foundry iron is best for ordinary foundry castings, because it contains the most carbon, and is softer and will remain fluid longer than either the mottled or white irons, yet it is not best for malleable castings, for the carbon in it is not combined with the iron, and in converting the castings into malleable iron the carbon is extracted from the iron without melting the castings, and if this class of iron is used the castings will be full of small holes after they have been malleableized, and will not have the required strength.

The iron that will make the best malleable castings is white cast-iron, for in this the carbon is completely

combined with the iron, and when it is abstracted from it by the annealing process, it leaves a perfectly sound and smooth casting. But in using this iron for malleable castings another trouble arises. The iron contains so little carbon that it will not retain its fluidity long enough to be run into light castings, and almost all malleable castings are very light; so that this class of iron cannot be used.

As the grey or No. 1 foundry iron contains too much carbon, and the white iron too little carbon, the best iron for malleable castings must be the mottled iron, which is between the two extremes. This iron is always used for malleable-iron castings, and none but the very best brands of cold-blast charcoal mottled iron will produce a good malleable casting.

Iron for malleable castings may be melted in a cupola or in either of the reverberatory furnaces. But the iron melted in a reverberatory furnace always produces by far the best castings; for the iron is not melted in contact with the fuel, as in the cupola, and it is not deteriorated by the impurities contained in the fuel. There is also the advantage that, should the iron contain too much carbon, part of it may be removed by the oxidizing action of the flame.

As most malleable castings are very small, they are generally moulded in snap-flasks, with greensand, from metallic patterns or match plates. The castings, before they are annealed, are as hard and brittle as glass, and they must be handled with care to prevent breaking. These castings are put into a tumbler or rattle barrel, where they are cleaned of all adhering sand, and become polished by mutual friction; to anneal them properly, it is very essential that thay should be thoroughly cleaned. The cleaned castings intended for conversion into malleable iron, are next packed into iron boxes, with alternate layers of fine iron scales from rolling-mills. The boxes are then closed at the top by a mixture of sand and clay, and all the cracks are carefully luted, to prevent the admission of air. The boxes are next put into the annealing oven, where they are subjected to a white heat, not sufficiently hot, however, to melt the boxes. They are kept at this heat for a week or more, and then allowed to cool off gradually. After the castings have been properly annealed, they are covered with a film of oxide of different colours, and resemble in appearance that kind of Champlain iron ore called peacock ore. These various colours of the oxide are a sign of good malleables. This adherent oxide is removed from the casting by another passage through the rattle barrel, and the process of malleable-iron making is finished.

Powdered iron ore is sometimes used in place of iron scales, but it is not so good, for it contains more or less silica and earth, which, at the temperature of the annealing oven, will fuse and form a slag or cinder, and prevent the oxidizing action on the castings. For this reason, scales are to be preferred, and care should always be taken to keep them as free from earthy matter as possible. In every "heat" or annealing operation, the scales part with some of their oxidizing properties, and before they are again used they must be pickled and reoxidized. This is done by wetting them with a solution of sal-ammoniac and water, and mixing and drying them until they are thoroughly rusted, when they are again ready for use. The annealing boxes were formerly made of soft iron, but at present they are mostly made of hard iron—the same as the castings are made of. The hard iron boxes become annealed the same as the castings, and will last longer than the soft iron boxes. These boxes are generally made about 20 in. long by 14 in. wide and 14 in. deep. They are set one on top of another in the annealing oven, but never more than two high. The lower one has a bottom cast in it, but the top one has no bottom, and is merely a frame set on the lower box. These boxes only last a few heats, and the small boxes are said to last longer than the larger ones.

There are several different kinds of annealing ovens in use, and some very important improvements have been made in their construction in the last few years. The best in use at the present time is one with a fire on each side of it, and so arranged that the flame from the fuel does not enter the oven or strike the boxes. This oven is not allowed to cool off, but is kept hot all the time, and at one end there is a door, through which the annealing boxes are removed while at a white heat, and are replaced by cold ones. The door is then closed, and the boxes heated to the required degree. This kind of oven is most economical in use, for it requires less fuel than any other, and is not injured by expansion and contraction in cooling and reheating, as the other ovens are. When annealing the castings in the oven, care should be taken to not have the temperature of the oven too high, nor the heat too prolonged, or the castings may be burned and hardened after they have been softened. After the castings have been thoroughly decarbonized by annealing in the oven, they are virtually a commercially pure iron, and are the same as wrought-iron without fibre, and fibre may be imparted to them by rolling or hammering. Yet these castings without fibre are sometimes equal to the best wrought-iron for strength, and may be bent double when cold without breaking them. (*Iron Age.*)

The process is conveniently applicable only to small castings, although pieces of considerable size are sometimes thus treated. Handles, latches, and other similar articles, cheap harness, mountings, ploughshares, iron handles for tools, wheels and pinions, and many small parts of machinery are made of malleable cast iron, or as steel castings. For such pieces, charcoal cast iron of the best quality should be selected, in order to ensure the greatest possible purity in the malleable product. The castings are made in the usual way, and are then embedded in oxide of iron—in the form, usually, of hematite ore—or in peroxide of manganese, and exposed to the temperature of a full red heat for a sufficient length of time to ensure the nearly complete removal of the carbon. The process with large pieces requires many days. If the iron is carefully selected, and the decarbonization is thoroughly performed, the castings are nearly as strong and sometimes hardly less malleable than fairly good wrought iron, and they can be worked like that metal. They will not weld, however. The pig-iron should be very free from sulphur and phosphorus. The best makers have usually melted the metal in crucibles having a capacity of 50 to 75 lb., keeping it carefully covered to exclude cinder and other foreign matter. The furnace is similar to that of the brass foundry, 2 to $2\frac{1}{2}$ ft. square, and the fire is kept up by natural draught. The temperature is determined with sufficient accuracy for the practical purposes of the iron-founder by withdrawing a portion on an iron bar. If hot enough, the drop burns on exposure to the air. If right, the metal is poured quickly. The "cementation," or decarbonization, is conducted in cast-iron boxes, in which the articles, if small, are packed in alternate layers of the decarbonizing material. As a maximum, about 800 or 1000 lb. of castings are treated at once. The largest pieces require the longest time. The fire is quickly raised to the maximum temperature, but at the close of the process the furnace is cooled very slowly. The operation requires 3 to 5 days with ordinary small castings, and may take 2 weeks for large pieces. This process was invented in 1759. Decarbonization is often performed, in the production of steel castings, by a process of dilution accompanied with possibly some "dissociation." By the preceding method the carbon takes oxygen from the surrounding oxides, and passes off as carbon monoxide (carbonic oxide); in the process now referred to the carbon of the cast iron is shared between the latter and the wrought iron mixed with it in the melting-pot, and a small portion may possibly pass off oxidized. The latter method has been practised to

some extent for a century. Selected cast iron and good wrought iron are melted down together in a crucible, and cast in moulds like cast iron. The metal thus produced contains a percentage of carbon, which is determined by the proportions of cast and wrought iron in the mixture. The amount is so small, frequently, that the castings can be forged like wrought iron. (Prof. Thurston, *Materials of Engineering.*)

Melting.—There is probably as much reason for changes in the plan of melting iron as in moulding jobbing work. Melters will sometimes get nervous at being ordered to charge up their cupola in as many different ways as there are days in the week. A foreman that understands his business very seldom lays out a system, or a table of charges, for his melter to follow day after day in a regular jobbing-shop. The foreman may have various reasons for wanting his melter to make all these changes. To-day he may want the cupola to melt extra fast during the first of the heat, and slowly after some heavy casting is poured, in order to have melted iron to feed with. To-morrow, seeing that some moulder will not get ready in season, this order may be reversed. As he does not want to keep his men late when it can be avoided, he orders the cupola charged, so that the men having small work can be pouring off while the large casting is being got ready. This casting, that perhaps weighs 5 tons, may not be thick in any of its parts, so as to require much feeding, and the bottom can be dropped soon after it is poured. In this way, the only moulders kept late are the ones that were going to keep the whole shop's crew behind, which, for a shop that pays overtime, would be expensive, and in any case is not pleasant for the men.

On some days the shop-floor may be covered with a class of work that is better for being poured with dull iron, and the next day the work may be such as to require very hot iron. Again, there will be heavy and light castings, requiring entirely different grades of iron; and to complicate matters, the foreman, if an observing man, will see that the brand of iron is not of the same grade as the last car-load.

Following are two of the many plans that may be adopted to meet different conditions. One is for melting special grades of iron, and the other to retain the bed in a cupola after melting a heat for a break-down job, or for a piece of casting that is wanted in a hurry.

The cupola man may receive instruction not to drop the bottom, but to prepare it to melt iron again in the course of 3 or 4 hours. The way to do this is as follows:—Leave the blast on until you are sure all the iron in the cupola is melted, and, instead of dropping the bottom, knock out the front breast, and with a bent hook pull out all the clinkering coke or coal and iron cinder that can be felt or seen. Then fill up the breast-hole with loose sand, and every 5 or 10 minutes take away the sand and pull out again whatever clinkers or iron cinders will have formed, repeating the operation for the first ½ hour or so, until you are sure that all the droppings of iron and clinkers are pulled out. After this, every ½ hour will be sufficiently often to clean the bottom out. The stopping up of the breast every time the clinkers are cleared out is done to prevent the fuel from burning away, and also to keep the clinkers and droppings of iron from being chilled with the air.

After the cupola is well cleaned out, there should be some fuel shovelled in, so as to freshen up and keep the fire in good burning condition. When the moulders have their mould or moulds about ready, make up the breast as usual, and shovel in the fuel for a bed, the same height as for a regular heat. After it gets to burning, charge up the iron wanted, put on the blast, and you will soon have your cupola melting iron again. The first 2 or 3 cwt. of iron is generally dull, and sometimes will have to be poured into a pig-bed. After this, the iron will come hot enough for ordinary casting.

The question of how large a heat a cupola run in this way would melt could

not be better answered than by the following:—A casting, the weight of which was about 2500 lb., was poured about 11 o'clock in the morning. The iron was all blown down, the breast knocked out, and the cupola treated as above described, until the time for the regular afternoon heats, which were never less than 12 tons. The blast was again put on, and after the first few hundred pounds, the iron was as good and as hot as usual. The time that the cupola was held from one heat to another was about 4 hours. The size of this cupola was a 5-ft. shell.

To prevent the mixing of different grades of iron when melted at one heat, has been the cause of a deal of thought and many experiments with foundrymen. Some foundry owners make a practice of melting only one grade of iron at a time. If they have a roll to cast, they will only charge up the iron weighed off for it. The blast will then be put on, and all the iron in the cupola melted and tapped out. The blast is then stopped and the bed renewed with coke. Another grade of iron is then charged up and all melted down. As many as 3 distinct blow-outs have been made during the same heat. The first was about 7000 lb. for a roll; the second, about 2000 lb. for soft work, and the third was common iron to finish off a heat of about 8 tons. The size of the cupola that this was done in was about a 4 ft. 6 in. shell. The objection to this style of melting is, that there is a little more coke used, and it takes ½ to 1 hour longer to run a heat off.

It seems almost an impossibility to run a straight heat, when there are 2 or 3 different grades of iron to melt, without having them mix more or less, and the less the weights of the different grades to be melted the more will they be liable to mix. For example: Charge an ordinary cupola, with a regular feed of a special grade of iron, with the usual amount of fuel on top, and so on, charging with distinct grades of iron. As the grades of iron melt, pour some castings, the weight of which should not be less than 50 lb. On the following day, melt the special grades of iron by themselves, and pour some castings, and then compare the runners and gates, and you will see that there is a difference.

It is generally known that hard iron will melt sooner than soft iron, and most foundrymen, when making a casting of hard iron, have the hard iron charged first, to make sure of having the casting of good sound iron and of the grade wanted. If they have soft iron to run, it is generally charged on the top of the hard iron. This plan cannot always be approved of, as there are always more or less particles of any grades or charges of iron left remaining among the fuel and on the bottom and sides of a cupola, and which will affect 2 or 3 other charges.

A plan that works well, when there are 2 charges of soft iron wanted, is to melt the hard iron first; then, instead of putting the soft iron directly on the top of the hard iron, charge about 2 charges of common iron—either soft or hard. On top of these the soft iron will be charged. After all the hard iron is down, then the common is tapped out, until, by the number of ladles carried off, it is apparently all melted. At this point, the soft castings are poured according to the degree of softness wanted. The softest casting wanted, if there have been 3 charges of soft iron, should be taken from what is thought to be the middle or second charge.

In some cases, where only a small amount of very soft iron is wanted, you may charge up the soft iron on the top of the bed, which should be burning well, and should not have in as much fuel by 4 in. to 6 in. as for ordinary heats. This iron will be put in ½ to 1 hour before any other charge, and when all is ready to have the rest of the charges put in, make the first charge of fuel (that which is placed between the first and second charges of iron) a large one—as much larger than usual as the bed was left low. By this means, the large charge of fuel takes a longer time to get hot enough to melt the upper charge of iron, and when the first charge

of iron is melted, the second, or large charge of fuel, will come down and raise the bed up to the proper height to run the balance of the heat off. By this plan, hard iron has been charged on the top of soft iron.

When not taking out the soft iron too closely to the amount charged up, the castings have been as soft as if the hard iron had never been charged up. It is in having only small quantities of different grades of iron to melt, that there is serious trouble with their mixing together. With large quantities, there is more chance of having castings the grade wanted; but even then the melter must use judgment in seeing that the iron is charged as it should be, and the foreman should be watchful, so as to know that the iron is taken away from the cupola as the grades melt or come down. There is nothing about a foundry that requires such changes in its management as a jobbing foundry cupola. (T. D. West.)

Tempering.—This term is here employed in its widest sense, embracing hardening, case-hardening, softening, toughening, and annealing. It will be convenient first to discuss the principles advanced by different metallurgists as underlying the operation of tempering, and then to proceed to enumerate the various recipes in vogue.

The hardening of iron and steel has recently been studied in an able manner by Prof. Akerman, of Stockholm, in a paper read before the Iron and Steel Institute, of which the following is an abstract:—

Effects of hardening.—The knowledge of the effects of hardening, especially on iron, is by no means so complete, and still less so generally diffused, as is desirable. It is necessary in the first place to make ourselves acquainted with the nature of hardening. If we inquire what are the circumstances on which it depends, whether more or less of the so-called "combined" carbon in a malleable iron or steel exists as "hardening" or "cement" carbon, it appears that the latter is changed into the former by a heating to a red heat, succeeded by a violent forcing together, continued until cooling is almost complete; while hardening-carbon, on the other hand, is changed into cement-carbon by long-continued heating followed by slow cooling without extra compression. In the case of strong hardening of hard steel, we have the most powerful compression, for the rapid cooling produces a great difference of temperature between the outer and the inner layers of the piece, the more cooled exterior layers compressing the interior with greater force in proportion, partly as the latter are expanded by being more strongly heated, and partly as the limit of elasticity of the substance is high, so that there is not too great a loss of the compressing force by the extension of the exterior layers. Again, that hammering favours the conversion of cement-carbon into hardening-carbon, or the more intimate union of the carbon with the iron in which it occurs, more than rolling, may at least occasionally to some extent be attributed to the more powerful compression exerted by the hammer, but still more to the circumstance that the iron or steel, when the rolling is ended, commonly has a far higher temperature than when it has been drawn out under the hammer. For if the iron or steel be still red-hot when the drawing is finished, a part of the carbon converted into hardening-carbon, or more intimately united with the iron during the compression to which it has been subjected, may be again changed into cement-carbon during the succeeding slow cooling. There is thus a very complete correspondence between the occurrence of hardening and cement-carbon and their mutual conversion in malleable iron and steel on the one side, and the relations of the combined carbon and the graphite in pig-iron on the other.

Proceeding to the hardening, we find that experience has sufficiently shown that its effect mainly depends upon the content of combined carbon in the iron, upon the differences of temperature between the iron or steel and the hardening fluid, and further on the rapidity of

the cooling. The last-mentioned again is dependent on the quantity of the hardening fluid, its specific gravity, power of conducting heat, specific heat, boiling-point, and heat of vaporization. Of the 4 liquids, mercury, water, oil, and coal-tar, therefore, the first-named hardens much more powerfully than water, water considerably more powerfully than oil, and oil more powerfully than coal-tar. Further, the hardening power of water is altered not only by differences of temperature, but also by the addition of different substances, which change its properties in the respects just mentioned. Finally, the rapidity of cooling, so important for the degree of hardening, is also dependent on the way in which the piece is held down into the hardening fluid. For if it be kept still in a hardening fluid of low specific gravity and small conductivity and specific heat, the quantity of the hardening fluid is not of the same importance as if the piece be unceasingly moved about in it; but in the latter case the cooling of the piece is apt to be unequal, inasmuch as by the moving about the front parts are cooled somewhat more rapidly than the back ones. This is also the case if by hardening in running water we make the quantity of the hardening fluid, so to speak, unlimited. The front part of the piece, or that which is turned up-stream, is then, of course, cooled most rapidly; and in order in such a case to attain an even hardening, it is necessary to turn round the piece rapidly and unceasingly. The layer of steam which, in the case of hardening in a substance so easily converted into vapour as water, is formed around the warm piece, is an obstacle to the contact of water with it, and thus diminishes the speed of cooling along with the degree of hardening which is dependent upon it; but if care be taken that in one way or another the steam be easily and rapidly carried away as it is formed, the rapidity of cooling, on the other hand, on account of the great heat of vaporization of water, is very considerably promoted by this conversion into vapour. Small pieces, therefore, are also very well hardened in water-dust finely distributed by means of a stream of air or steam; and the highest degree of hardening may, according to Jarolimek, be attained in this way with so moderate a quantity of water that all the water-dust which comes into contact with the warm piece is brought by it into the form of steam. These influences exerted by the formation of steam, must also be taken into consideration when, in order to attain an inferior degree of hardness, warm water is used instead of cold. It cannot accordingly be denied that there are many factors, exceedingly difficult of calculation, which exert an influence on the speed of cooling, and thereby on the degree of hardness. Nor is it much to be wondered at that mistakes are readily committed in hardening, and that great practice is required in order to be able confidently to reckon on a certain effect; and finally, that a workman accustomed to hardening considers that only a single method which he has been in the habit of employing can be used for a certain purpose, while another equally skilful workman can only attain the same result by a method essentially different. It further appears that the rapidity of the first cooling, from the 1112° to 1292° F. (600° to 700° C.), to which steel has commonly been heated, to 572° to 752° F. (300° to 400° C.), has a manifold greater influence on the degree of hardness than the succeeding cooling. Thus, Jarolimek has shown that steel wire may be very well hardened both in watery vapour and in molten tin, lead, and even zinc, though the last-named metal does not melt under 752° F. (400° C.), while the cooling of the same steel wire from 572° or 752° F. (300° to 400° C.) to 32° F. (0° C.), does not cause any true hardening, however rapidly it may proceed. In order that steel wire may be hardened in this way, it is not, however, allowed to remain any considerable time in the molten bath of metal, for by long-continued heating, following such a hardening, the degree of hardening is afterwards diminished more and

more. If it be taken out again after being dipped in the bath for quite a short time, and afterwards allowed to cool in the air, the degree of hardening for small articles is equal to that attained by ordinary hardening with the tempering following upon it.

Of the effects produced by hardening, it was in old times mainly the hardness on which attention was fixed, and from this is derived the old saying that a substance does not take hardening if it do not thereby become so hard that a common file can no longer exert any noteworthy influence upon it. From time immemorial a distinction has also been made between iron and steel in this way, that the former, with common hardening in water, is not hardened in the sense just indicated, while steel, on the contrary, is hardened. We sometimes hear it brought as an objection against the old way of distinguishing between iron and steel, that it is difficult to determine whether a piece, after common hardening in water, is to be considered as having taken true hardening or not. But such a reason is in fact quite unwarranted, because, according to the old view, only the varieties approximating most closely to each other of the hardest iron and the softest steel can be mistaken for each other, and such a mistake is indeed of little importance when compared with the great mistake just referred to, of soft iron for soft steel. If it be wished wholly to avoid the possibility of making mistakes between hard iron and soft steel, this even ought to be attained very easily by the method of determination, in which a sharp-edged splinter of a certain mineral—felspar, for instance—scratches iron, although, after being heated to moderate redness, it has been suddenly cooled in cold water, while steel, after similar treatment, cannot be scratched by the same mineral. The substance which exerts the greatest influence on the increase of hardness by a certain hardening process is the content of combined carbon in the iron. Iron completely free from carbon is, even after hardening in mercury, as soft as before, and an otherwise pure iron, with at most $\frac{1}{5}$ per cent. carbon, does not become very much harder by hardening; but, on the other hand, as the content of carbon increases, the difference in the degree of hardness before and after hardening increases more and more, so that the boundary-line between iron and steel lies in general at a content of carbon of about 0·4 per cent., this depending, however, upon the iron's content of certain other substances, which also exercise some influence on the degree of hardness. In the closest connection with the increase of the hardness by hardening stand the raising of the limit of elasticity, the breaking strain or ultimate tensile strength, and the diminution in ductility. Unfortunately, the researches that have been carried out regarding these points are not yet numerous enough to enable us with figures to express completely all the changes in these respects which are caused by hardening in iron and steel with different contents of carbon, but sufficient experiments have already been made to give us somewhat satisfactory ideas on this point. A comparison shows that the effect of hardening is in general less in the case of the weld-iron, loose or open in its texture, than in that of the dense or compact ingot-iron; but in proportion as the former even is denser or freer of cinder, hardening has a greater effect upon it, as is shown by a comparison both of the more compact Lesjöfors iron with the other sorts of iron refined in the open hearth, and of the more compact Surahammar with the other sorts of puddled iron. In order to augment considerably the strength of ordinary puddled iron, a French iron-manufacturing company increases the hardening power of water by adding to it sulphuric acid. The cooling effect of water is thereby raised, and thus also its hardening power; but in order to prevent the corrosion and rusting of the iron, it would be advisable to endeavour to attain the same result in some other way, as by the addition of some salt that would have less corro-

sive action upon the iron. Hitherto we have considered the influence of hardening upon iron, but if we proceed to investigate its action on steel, we find that it is shown chiefly by an increase in its hardness and a diminution in its ductility greater in the same proportion as the steel is richer in carbon and the hardening fluid employed is more powerful in its action. At the same time that steel with an increased content of carbon becomes, through a certain hardening, all the harder, it becomes thus at the same time more brittle; and in the closest connection with this is the fact that in the hard steel, rich in carbon, the limit of elasticity is increased by hardening much more than the ultimate tensile strength, so that these in the strongly-hardened hard steel even coincide. Provided the method of hardening is adjusted to the degree of hardness of the steel, so that it is less powerful in the same proportion as the content of carbon in the steel is greater, it may be asserted that the breaking weight is increased by hardening, even in the case of steel; but if the hardening be too strong, the ultimate tensile strength of hard steel is thereby diminished quite rapidly; or the steel breaks in pieces of itself either during the hardening or a short while after. It is on account of this brittleness or deficient ductility that the hardened steel is usually tempered or heated to 392° to 572° F. (200° to 300° C.), for thereby its ductility is somewhat increased, but its hardness at the same time also diminished. This is the case most of all with the outer layer, which of course is that which it is desired should be hardest, and to avoid this and the trouble and loss of time connected with the process just mentioned, the hardening itself is sometimes instead so modified that its effect is equal to that of a more powerful hardening followed by tempering. For such a method, however, more than common skill and practice are required, and it is therefore comparatively seldom used. For attaining this end is sometimes used a less powerful hardening fluid, and sometimes a warm instead of a cold fluid, and sometimes the piece is held only a short time in the hardening fluid, and is taken out while it is yet warm in its interior and allowed finally to cool in the air. Further, the material may, for this purpose, be heated more gently, but it must be kept in mind in connection with this that a less heat than a gentle red heat (cherry-red) in general does not induce any proper hardening; and, on the other hand, that tool steel cannot in most cases be heated to a higher temperature than that just indicated without running the risk of becoming, by hardening, too brittle. It is thus properly only for soft steel and iron that the degree of heating can be varied to a greater extent, but it holds good specially for the latter, and above all for weld-iron, that the temperature must be considerably higher than for hard steel, if the proper action of hardening is to be attained. The more strongly and the longer the iron or steel after hardening is again heated, with slow cooling supervening, the more completely are the effects of hardening removed; and care ought therefore to be taken in tempering; but here we have a good help in the different colours of tempering which follow one after the other. On the appearance of fracture also, the hardening has an influence, the grain becoming finer.

Causes of Hardening.—Having discussed in detail the effects of hardening on the different varieties of iron and steel, we shall endeavour to ascertain the intimate causes of these effects. That they increase with the rapidity of cooling, and thus are a consequence thereof, has been already shown; but the question is, how the rapidity of cooling can produce such effects. The hypothesis that is still most common is that which assumes that a rapid cooling gives us the *status quo*, or the state into which the substance was brought by the heating which immediately preceded the rapid cooling, and the action of the hardening would in such a case only be a result of the heating itself, inasmuch as the rapid cooling only, so to say, fixed

the warm condition, or, in other words, made it possible for the substance, even in a cold state, to show itself as it was during the heating. During slow cooling, on the other hand, the molecules would have opportunity to group themselves in a more crystalline manner, and hence the coarser grain. But if the molecules can move about in this way during the cooling, they may well do so to a still greater extent at the highest temperature to which the substance has been heated, for this grouping of the molecules is rendered possible just by the softening to a greater or less degree which the heating causes in the iron, and the softening is naturally greater the higher the temperature is. That, first of all, a violent compression must in such a case take place is self-evident, for we have now to do with a body heated from without, which therefore, at least when the heating has not been of all the longer duration, is apt to be warmer in the outer than in the inner layers. When now this body, by dipping in a hardening fluid, or in some other way, is exposed to a rapid cooling acting from without, the outer layers are cooled first, and the difference of temperature between the outer and the inner layers is greater the whole way through in the same proportion as the method of cooling is more powerful, and the cooling is accompanied by compressing or forcing together, and the more the outer layers have been cooled in proportion to the inner, with the greater compressing force must the former work upon the latter, which by their resistance react upon the outer layers. The compressing force is, however, by no means exclusively dependent on the rapidity of cooling, but also on the compactness of the material; for the smaller this is, the more readily does the material allow itself to be compressed, and the less accordingly becomes the resistance which the interior develops against a certain compressing force, so that no great resistance is ever experienced in such a case. In this way is explained the fact, which has already been pointed out, that the effect of hardening is greater on the compact ingot-iron than on the weld-iron, which is looser in its structure. Further, the compressing force is naturally in a very high degree dependent on the limit of elasticity of the material; and the smaller this is, the more easily are the outer layers stretched by the resistance of the inner, and the smaller, therefore, is the portion of the contracting force which can be made available as actually compressing. All substances which in iron increase its limit of elasticity, ought therefore to have an influence on its power of hardening; a fact which has also been confirmed by experience, inasmuch as not only carbon, but also manganese, silicon, and phosphorus, have shown themselves to have some influence in this respect. The action of the other substances, however, upon the degree of hardening is limited in comparison with that of carbon; and the explanation of this appears, as has already been pointed out, to lie mainly in the more intimate union between iron and carbon which a violent compression produces. As the union between these substances becomes more intimate, the influence of the content of carbon on the iron also becomes greater, and it is just an increased exertion of the influence of the carbon on the iron that is attained by hardening. If we now compare with this the influence of hardening as stated above, it appears that it only still further increases the degree of the properties just mentioned as dependent on a certain content of combined carbon, quite as if the content of combined carbon had been increased by the hardening; and in most complete correspondence with this stands the fact that the ultimate tensile strength is not continuously increased by the hardening; but if steel with a large content of carbon be strongly hardened, the limit of the increase of tensile strength is exceeded. The correspondence between the action of hardening and of a larger content of carbon is thus manifest in this case also. The diminution of the tensile strength by a too strong hardening of a highly carbonaceous

steel is, however, much more rapid than the corresponding decrease in consequence of the content of carbon being too large in the unhardened steel, but this difference is easily explicable by the great tension which a strong hardening must produce in the highly carbonaceous steel. When a hard steel is too strongly hardened, the larger pieces in particular readily break in pieces of themselves, which again is a natural consequence of the fact already mentioned, that the limit of elasticity in this case nearly coincides with the ultimate tensile strength, and therefore when the resistance of the inner layers against the contraction of the outer becomes so strong that the limit of elasticity is exceeded, fracture of the hard steel readily takes place, instead of the extension which would have occurred in the outer layers of a less hard steel. The same correspondence between the influence of hardening and an increased content of carbon also prevails in respect of ductility, hardness, and fineness of grain. The first of these properties diminishes and the two others increase with the content of carbon, and corresponding changes are produced by hardening.

Another proof that the effects of hardening depend on the oft-mentioned compression is afforded by the behaviour of burnt iron in hardening. Burnt iron, as is well known, is the name given to an iron which, through too long-continued or strong heating, has had the opportunity of assuming a crystalline texture, with the brittleness which accompanies it on account of diminished cohesion of the crystals. The disposition to such a crystalline segregation is less in proportion as the iron is both more mixed with cinder and freer from certain substances; but the more carbon, and in particular the more phosphorus, it contains, the greater is the liability of the iron to be burned, and the more care ought therefore to be taken with the heating, if it is not in consequence of this distribution into crystals to fall in pieces utterly, or at least crack, as soon as the drawing begins. An iron as good as free from these substances can, without danger of burning, be heated to the strongest welding heat, but with an increase of carbon in the iron all the more care must be observed in the heating, and this is rendered necessary in a much higher degree by an increased content of phosphorus in the iron. So long as the content of carbon in the iron is quite small, however, this detrimental influence of phosphorus is still rather limited, more particularly if the iron contains at the same time a good deal of manganese; but the greater the content of carbon in the iron, the more is the detrimental influence of phosphorus increased, and the first requisite of a really good steel is, therefore, that it contains as good as no phosphorus. An iron whose disposition to burn is so great that this detrimental change cannot in general be avoided, has from old times been called "cold-short," from the brittleness caused by its crystalline texture. But in this connection it must be kept in mind that the disposition to burn, increasing with the content of phosphorus, is not only counteracted by the presence of manganese and the absence of carbon, but also that the iron molecules in the puddled iron are intercalated with layers of a fine interspersed cinder, which is unfavourable to the formation of the coarse crystals which cause the brittleness. A certain content of phosphorus is therefore not so detrimental to the puddled iron, loose in its texture and mixed with cinder, as to the cinder-free ingot-iron, and if by the adoption of a suitable treatment the production of even the least sign of crystalline texture be prevented, a content of phosphorus rising to $\frac{1}{2}$ per cent. does no great harm to the iron, so long as it is in the non-crystalline condition just mentioned; but the difficulty is to avoid the crystalline texture in the phosphoriferous iron, and, if success is attained in this, to prevent the formation of crystals in the case of a possible future re-working of the iron in a warm state. Now, whether an iron which, from one cause or another, has a tendency to burn, becomes, after a certain heating,

burned or not, depends mainly on the degree to which it is afterwards drawn out; for the more an iron, which, when heated, has begun to be crystalline, is afterwards drawn out in a warm state, the less is the danger that the crystalline texture will remain in the fully-drawn iron. In this way it is explained why a greater degree of drawing out, and thus also larger ingots, are requisite for a more than for a less phosphoriferous iron. If, however, an iron after a certain heating, followed by drawing, still appears to be coarsely crystalline or burned, this burning can frequently be removed by heating the iron anew to a certain welding heat, properly adjusted to its content of carbon and phosphorus, succeeded by a new drawing out; but we must not make too sure that we can in this way always remove the burning or cold-shortness. In complete correspondence with this, experience has shown that burning can be removed by a corresponding heating, followed by hardening instead of by drawing; and this circumstance affords a new proof of the correctness of the view, that the effects of hardening must depend on the compression caused by the contraction, as it, like the drawing out, can remove the crystalline texture. In close connection with this, doubtless, also stands the circumstance that the hardening of an iron which contains much phosphorus but little carbon can even increase its ductility, for the somewhat crystalline texture of a phosphoriferous iron may be destroyed by hardening, whereby again its ductility is greatly increased.

"To the older observations noticed above has lately been added a new experience, which further confirms the correctness of the view that the effects of hardening depend on the compression caused by the contraction. The experience now referred to is that ingot-metal free from blow-holes can, without drawing, and merely by hardening followed by a new heating to redness, become quite equal to ingot-metal that has been drawn out. It is, at least if the content of manganese be not all the greater, only when the percentage of carbon exceeds 0·3 that the ductility suffers through hardening any loss endangering the strength of the material, and it therefore appears probable that in all the cases where special ductility is not demanded, it may not be necessary to reheat to redness castings poor in carbon after they have been hardened. The higher the temperature at which the reheating takes place, provided, however, it does not exceed a full red heat, the more is the ductility increased; while, on the other hand, the limit of elasticity and the ultimate tensile strength are thereby diminished until they descend to nearly the same minima which characterise ingot-iron or ingot-steel of the same composition which has been heated to redness after hardening. By modifying this reheating, on the other hand, it is possible to bring the hardened castings to intermediate stages of these qualities, quite as is the case with the hardened drawn iron or steel. The consequence of this must be that a drawn iron or steel—above all, when the drawing, as in the case of hammering, has been continued to a low temperature—loses in limit of elasticity and ultimate tensile strength by heating to redness followed by slow cooling; while an undrawn ingot may increase to some extent in these properties, although in a smaller proportion, according as the degree of heating was less and the cooling slower. On the other hand, by sufficiently rapid cooling or actual hardening, the oft-mentioned properties are increased in the material to a higher degree than can be attained merely by drawing; but by renewed heating this excess can be again removed."

Influence of Carbon.—Prof. Chandler Roberts has shown that in soft, tempered, and hardened steels respectively, the carbon present has distinct modes of existence, as is indicated by the widely different action of solvents on the metal in these 3 states. The question whether the carbon in steel is combined chemically or merely dissolved mechanically has been much discussed. Roberts inclines to the opinion that in white cast-iron and steel the carbon is

merely dissolved. The phenomena of hardening and tempering steel witnessed in the workshop are briefly these: a piece of steel (by steel in this connection is understood a piece of the special metal which is sold as tool steel, shear steel, crucible steel, &c.) is forged into the shape of a tool, heated to redness, or as high a temperature as can be reached without running a risk of "burning" it, and, while still red, dipped into water and held there until cold. The metal is now found to be changed in its mechanical properties: it is technically known as "dead-hard"; that is, it is as hard as it is possible to make it—brittle, and proof against a file or drill. If the piece is now placed on a hot plate, the surface will first assume a light straw colour, and as the temperature increases, the tint will change, the order being deep yellow, red, brown, purple, blue; at which last-named colour the metal, instead of being brittle, is springy and resilient. The first process is known as hardening; the second as tempering, or drawing down to a yellow, brown, or blue temper, the exact temper being practically obtained by dipping the metal in water as soon as the desired colour is reached. These are the phenomena in brief; in the workshop different brands of steel are treated in various ways, and the peculiar dips and tempering liquids are looked upon as trade secrets; but in principle the processes are as described. The problem to be solved is, why steel heated to redness and suddenly cooled should become so very hard, and when subsequently reheated should become softer and springy. So far as known, the properties of the steel depend upon the quantity of carbon, and upon its condition. The action of slowly-oxidizing agents upon cold rolled steel, made by the cementation process, appear to indicate that the carbon in such steel exists in the form of iron carbide, and is not mechanically diffused in the mass as simple carbon. The iron carbide resists the action of the oxidizing agents, which readily attack the iron through which it is distributed; but whether all kinds of steel possess this alloy of iron and carbon remains to be proved, although for about half a century it has been suggested that tempered steel is a true alloy of carbon and iron, the carbon being present in varying proportions according to the temperature, and being rendered permanent by the sudden cooling. The case of chilled cast-iron is analogous, although in that the hardening is effected with liquid metal, and not with solid, as in the case of steel. The surface of cast-iron is case-hardened by heating it while closely surrounded with carbonaceous substances, the sudden cooling shutting up the carbon, and converting the skin into a kind of steel. The presence of carbon is visible to the eye in cast-iron, but the chilled portion is uniform in structure. Soft steel shows a high degree of molecular rigidity as compared with the hardest iron, but far less than that of tempered steel; which fact, Prof. Hughes thinks, indicates that in its softest state steel is still an alloy, though only feeble quantities of carbon may be held in that condition. Hard-drawn iron shows that mechanical hardening has not diminished the freedom of the molecules in any great degree; but if the iron is even slightly alloyed with tungsten, sulphur, or other substances, it loses its molecular freedom. (*Eng. Mech.*)

Influence of Temperature. — Perhaps the best method ever discovered for tempering steel, resulting in hardness, toughness, and elasticity combined, is that followed in hardening the blades of the famous Damascus swords. The furnace in which the blades were heated was constructed with a horizontal slit by which a current of cold air from the outside entered. This slit was always placed on the north side of the furnace, and was provided on the outside with a flat funnel-shaped attachment by which the wind was concentrated and conducted into the slit. The operation of tempering the blades was only performed on those days of winter when a cold strong north wind prevailed. The sword-blade, when bright red hot, was

lifted out of the fire and kept in front of the slit, and by this means was gradually cooled in the draught of air. It acquired the proper degree of temper at the single operation. From this account it may be seen that gradual cooling is to be preferred to sudden cooling. While water has been used in the process of tempering for a long time, it was only at a comparatively recent date that hot water was used in place of cold, having various temperatures for various kinds of steel. For instance, for springs, the steel must not be made more than red-hot, and tempered in water heated to 150° F. (65½° C.). Low spring steel containing 0·002 to 0·004 of carbon, when made red hot and plunged into boiling water, has its tenacity and elasticity increased without its softness being altered. The colder the water, the more coarsely crystalline is the fracture, and by using hot water the fracture becomes more finely granulated in proportion to the temperature. By experiment it has been demonstrated that red-hot steel plunged into water at a temperature of 35° F. (2° C.) will be as brittle as glass, but when plunged into water at 212° F. (100° C.), it will be annealed and toughened. Water is not essential in the process of tempering. The only necessary condition is that of temperature, and other bodies than water may be used for contributing the right degree of heat. There are various liquids which can be heated to a higher degree than that named without requiring to be kept in a close boiler; such liquids are oil, melted tallow, wax, pitch, &c. Concentrated solutions of various salts in water make its boiling-point higher. It is substances of this kind which constitute the various tempering pickles. That the chemical constituents of the matter have nothing to do with its effects, but that it is only a question of temperature, is conclusively proved by the fact that when cooled below the freezing-point of water it by no means produces a fine granulated fracture. Oils and fats do not cool off the metal as rapidly as water. The boiling-point of water is comparatively low, and the latent heat of the steam is not very great. Its evaporation therefore carries off the heat which is in the steel with great rapidity. In using oil or melted fats it is not necessary to heat them very much; oil of 100° F. (38° C.) will be equivalent in its effects to boiling water. Jewellers and watch-makers do not temper their drills in water, as this makes them so hard as to be quite brittle. They use oil instead, or they stick the hot drill into solid sealing-wax, pulling it out quickly and sticking it in a fresh place, and repeating the operation until the drill is too cold to enter. Mercury, which is a good conductor of heat, has been used to make steel very hard; by its conductive properties it cools the steel quickly, while its evaporation aids in carrying off the heat rapidly. (*Blacksmith and Wheelwright.*)

Classifying Steels. — The steel of which all cutting tools are made depends more, for its real value, upon the degree of its temper than on the quality of the steel itself. A piece of untempered steel, even the finest grade, will under ordinary conditions not cut at all; while a piece of steel of inferior quality may be made to cut well if judiciously hardened and tempered. While the capacity of steel to cut is mainly due to the temper, the durability of the cutting edge is determined by the quality of the steel and its adaptability to the kind of work upon which it is employed. Hence, it is that, for cutting tools, the best cast-steel is employed. The degree of temper is varied to accommodate the nature of the duty. The cost of steel of which a tool is made is of very little importance compared to its efficiency, because this cost is very little in comparison with that of performing the duty. For example, a steel turning-tool weighing but 2 or 3 lb. will cut off many thousand pounds of iron, the operation lasting perhaps several weeks. The speed at which this tool will cut, or, in other words, the time it will take to cut off a given amount of iron, will vary 30 or 40 per cent. from a very slight differ-

ence in the quality of the steel of which the tool is made. The cost of the operator's time is so much greater than that of the steel used up in a given time, as to render it, even in the case of cheap labour, always economical to employ the best steel. With a given quality, however, the efficiency depends more upon the skill employed in the forging, hardening, and tempering of the tool, as well as upon its shape.

The art of hardening and tempering steel as applied to cutting tools is much more simple than when the same operations are employed to give steel elasticity as well as durability of form, or to give durability to pieces of slight and irregular form with sufficient hardness to withstand abrasion. The reason of this is that for tool purposes a special and uniform grade of steel is readily obtainable, which is known as tool steel. Special sizes and grades are made to suit the manufacture of any of the ordinary forms of tools. The steel purchased under the cognomen of steel, whether crucible or otherwise, and though of the same make and brand, may vary so much as to seriously affect the degree of hardness or temper obtained by any specific process. Most of the difficulties met with are in obtaining a uniform degree of temper, or in tempering without loss from water cracks, checks, &c. These defects may arise from rigidly adhering to some special process of hardening, and can be overcome by varying the method to suit the quality of the steel. Very few, especially of American steels, are as yet sufficiently uniform to render it practicable to employ an unchangeable method of tempering, and to this fact is largely due the importation of particular brands of foreign-made steel. Manufacturers of special tools, such as saws for example, find that they must either manufacture their own steel or import some well-known brand, and this in the case of most articles manufactured that require a fine and uniform degree of temper. This is not so much due to the good quality of the article, as to a precise knowledge of the process necessary to temper such steel. There is as yet no known method of practically ascertaining in workshops the quality of a piece of steel, unless it be by use. As a rule, the steel that shows a fracture of fine dull grain, the face of the fracture being comparatively level, is of better quality than that showing a coarse or granulated surface: brightness denoting hardness, and fibrosity toughness.

The soft steels, approaching more or less in their nature to wrought-iron, are exceedingly troublesome to harden and temper to a uniform degree, because of the difficulty experienced in producing them of uniform grade. Many kinds of these steels are made of so low a grade as to render it hard to determine the line of demarcation separating them from wrought-iron. With the object of having universally adopted names which should indicate the nature and the distinction between iron and steels, an International Committee was appointed at Philadelphia by the Institute of American Mining Engineers; they resolved that the following should be recommended:—(1) That all malleable compounds of iron, with its ordinary ingredients, which are aggregated from pasty masses, or from piles, or from any form of iron not in a fluid state, and which will not sensibly harden and temper, and which generally resemble what is called wrought-iron, shall be called weld-iron (Ger. *Schweisseisen;* Fr. *fer-soude*). (2) That such compounds, when they will from any cause harden and temper, and which resemble what is now called "puddled steel," shall be called weld-steel (Ger. *Schweiss-stahl;* Fr. *acier-soude*). (3) That all compounds of iron, with its ordinary ingredients, which have been cast from a fluid state into malleable masses, and which will not sensibly harden by being quenched in water while at a red heat, shall be called ingot-iron (Ger. *Flusseisen;* Fr. *fer-fondu*). (4) That all such compounds, when they shall from any cause so harden, shall be called ingot-steel (Ger. *Fluss-stahl;* Fr. *acier-fondu*). The main line of demargation

here laid down lies in the capability to harden. Steel which will harden from any cause—that is to say, by heating to any temperature and using any quenching liquid—is termed weld-steel. That which will harden by being heated to redness and quenched in water is termed steel.

Testing Steels.—Prof. Kich, of Pragne, after several experiments with nitric, sulphuric, and hydrochloric acids, and their combinations, with mordants composed of the salts of copper, &c., has arrived at the conclusion that a mixture of equal parts of hydrochloric acid and water, to which is added a trace of solution of antimony, constitutes a mordant especially applicable for the purpose of testing iron and steel. The last ingredient, which was recommended to him by Prof. Gintl, renders the surface attacked more capable of resisting oxidation, and has the effect, after well washing with hot water and the application of a coat of protecting varnish composed of damar resin, of preserving the surface attacked sufficiently pure. The method of proceeding is always to surround the surfaces, previously prepared by means of a file or hone, with a wall of wax fully $\frac{3}{4}$ in. high, the acid, heated to a temperature of 53° to 86° F. (12° to 30° C.), is poured on to the surfaces, and soon begins to act, as will become manifest by the disengagement of gas. In winter, owing to the low temperature, the operation cannot be performed so favourably. Its duration is usually 1 to 2 hours, and it should be continued, as a general rule, until the texture of the iron is exposed. The progress of the action may be easily ascertained by pouring out the acid every $\frac{1}{2}$ hour without breaking the wax border, removing by means of a brush or piece of rag the carbon (graphite) deposited on the surface, washing, and again pouring on more acid if the action appears insufficient. If the antimony chloride has been added to the acid in proper proportion, but little time will elapse, after the action has commenced, before it will begin to throw down a black precipitate. This is easy to distinguish from the graphite, inasmuch as the latter is not very appreciable, when for about $1\frac{3}{4}$ pint is added only a single drop of the concentrated solution of antimony chloride, which is sufficient. When the action of the acid has been continued long enough, the wax wall is destroyed, and the surface of the iron is washed by means of a brush with several waters, the first of which is rendered slightly alkaline by the addition of a little lye; it is then carefully dried, and a coat of varnish is applied. If, at the end of a few hours, there are any signs of oxidation, the varnish must be dissolved with spirit of turpentine, the oxide removed, and the varnish again applied. The indications given by the different kinds of iron are as follows:—

Soft or fibrous iron, when of very good quality, is attacked by the acid, even when the action is continued for several hours, in a manner so uniform, and with an elimination of the carbon so limited, that the surface acted upon retains a dull lustre—a few incised specks and cinder-like holes being only observable.

Fine-grained iron gives exactly the same indications; the surface generally remains uniform, but it is not quite so bright.

Coarse-grained iron and hot-short iron are attacked by the acid with much greater energy than the 2 kinds above mentioned. Even at the end of about 10 minutes the surface, especially that of the latter kind, becomes quite black. If the acid be allowed to act for nearly $\frac{1}{2}$ hour, a black muddy deposit (*schlamm*) may be removed by washing, and no amount of washing will prevent the surface from remaining black; there will also be a considerable number of small holes distributed over the surface. Some portions of the iron are generally attacked more deeply in this way; others, although they may have become black and a little porous, are better preserved. This appearance will be the more manifest if, after about an hour's action, repeated washing and drying, a fine file be passed over the surface.

Malleable iron or annealed iron be-

comes rusty, as is well known, more readily than wrought iron; but an interesting fact is that the action of the acid is very violent and irregular.

Puddled Steel. — The colour, after being treated with acid and washing, is grey, and of a tolerably uniform shade, the weldings being but little apparent.

Blister Steel.—The appearance exhibited is very like that of puddled steel, and the weldings are also but slightly apparent.

Bessemer Steel : Cast Steel.—The surfaces of these steels are uniformly grey—the non-homogeneous parts are rare, and but little apparent. The softer the steel the more approaching to grey is the colour. The action of the acid produces very fine fissures. In a sample of Mushet steel the prepared surface was perfectly uniform, but after the treatment with acid narrow transverse fissures were observed over the whole extent. It is probable that the proportion of titanium in this steel was the cause that the surface attacked presented the dark grey colour.

The old blacksmiths' method of calling that steel which can be hardened, is one recognized method. To harden, however, is one thing; to harden when heated to a definite degree, is another; and to possess a definite degree of elasticity when tempered to a particular point of temperature after hardening, is yet another. So that, in the absence of great uniformity in the grade of the metal, the blacksmith or the temperer must rely upon his judgment and perception. If under a given process the work is not considered hard enough, he may heat the metal to a greater temperature, providing its shape and size will admit of that without injury, or causing it to crack in the quenching. In this case he will try to make up for the deficiency in the metal to temper, by chemical additions to the quenching liquids.

Supposing that steel as operated upon be of uniform grade, the operation of the hardener would not always make it uniform, because steel decarbonizes somewhat by being heated; hence a small tool deteriorates by being heated in the open fire, and one often heated to sharpen or repair suffers in proportion. From all these and other considerations, hardening and tempering processes of steel differ according to the size and nature of the work, the amount of uniformity required, and the duty to which the work is to be put. The only information of value to the practical man is such as will instruct him in the practice of the workshops, giving the conditions and the processes in connection with each other.

Colour Tests.—If we heat a piece of cast-steel to redness, and plunge it into clean water until its temperature is reduced to that of the water, the result will be that the steel will be hardened. The degree of the hardness will depend upon the quality of the steel, the temperature to which it was heated, and to a small degree upon the temperature of the water in which it was cooled. In any event the operation will be termed hardening. If we reheat the steel, a softening process will accompany the increasing temperature, until upon becoming again red-hot it will assume its normal softness, and if allowed to cool in the atmosphere the effects of the first hardening will be entirely removed. If, however, after the steel is hardened, we polish one of its surfaces and slowly reheat it, that surface will assume various colours, beginning with a pale yellow and ending in a blue with a green tinge, each colour appearing when the steel has attained a definite degree of temperature; hence by the appearance of the colours we are informed of the temperature of the steel, or, in other words, how far or to what extent the resoftening has progressed. This fact is taken advantage of by the machinist to obtain in steel any required degree of hardness less than that of the absolute hardness obtained by hardening, and is termed tempering. The temperature at which these respective colours will appear are as follows :—

Very pale yellow .	430° F. (221° C.)
Straw yellow . .	460° F. (238° C.)
Brown yellow . .	490° F. (254° C.)
Light purple, . ,	530° F. (277°C.)

Dark purple . . .	550° F. (288° C.)
Clear blue . . .	570° F. (299° C.)
Pale blue. . . .	610° F. (321° C.)
Blue tinted with green	630° F. (332° C.)

To say, then, that a piece of steel has been tempered to a straw colour, implies that it was first hardened and then reheated until the straw yellow appeared upon it, the temperature having arrived at 460° F. (238° C.), and that the reheating process was then discontinued. The presence of the straw colour, however, while evidence of temperature to which the heating took place, is no indication of the actual degree of hardness of the steel, because that depends upon the degree to which the steel was hardened before the colour test tempering was resorted to. And since the degree of the first hardening depended upon the quality of the steel, the degree to which it was heated, and the temperature of the water in which it was cooled, it follows that the above quality, heating, and temperature must be uniform in all cases if uniform results are to be reached. The higher the grade of steel, the lower the temperature at which it will harden, and the harder it will be if cooled in water from a given temperature; but any degree of hardness obtained from a temperature equal to or less than the highest at which a colour would appear—that is, 430° F. (221° C.)—will obviously be representable under the colour process by a colour, providing, of course, that the steel was first thoroughly hardened.

The colour-scale forming the frontispiece to this volume represents the tint assumed by ordinary steel when, after hardening, it is "let down" to the temperatures recorded on the left margin; while the names of the tools are arranged on the right, opposite the shade of colour to which they are tempered. The scale has been prepared in accordance with the practice of some of the best authorities, and is based upon a somewhat similar but less complete one published by the well-known metallurgist, Joshua Rose, to elucidate some articles on tempering in the *Scientific American*.

Hardening and Tempering defined.—It is manifestly desirable to obtain any required degree of hardness by a single process, if possible; hence by heating a known quality of steel to a definite temperature, and quenching it in water or other liquid or mixtures maintained at about an even temperature, the colour test is becoming, in some cases, dispensed with, the conditions of heating and cooling being varied to give any degree of hardness from the highest attainable down to normal softness. Another and very desirable method of hardening and tempering is to heat in a flue of some kind maintained at the required temperature over the fire, and cool either in water or a quenching or cooling liquid, and then, instead of employing the colour test, to provide a tempering bath composed of some substance that will heat, in the open air, to a temperature of about 450° F. (232° C.). By placing the articles (after hardening them) in the tempering bath, and heating it to a temperature equal to the colour of temper (under the colour test) required, we have but to cease supplying heat to the tempering bath when a thermometer standing therein marks the required temperature, and a uniform degree of temper will be given to all the articles; and the operation will occupy much less time than would tempering either individually or collectively by the colour test, because a liquid is much more easily kept at an equal temperature throughout its mass than are the heated sand, hot pieces of iron, or iron tubes resorted to in tempering by the colour test. Another method of tempering, which, if capable of reduction to uniformity, would be the quickest and hence most desirable of any, is to heat the steel to a definite temperature, and cool or quench it in a liquid having sufficient greasiness or other quality which acts to retard its retraction of the heat from the steel, and thus give a temper at one operation. As an example of this kind of tempering, it may be mentioned that milk-and-water, mixed in proportions determined by experiment upon the steel for which it was em-

ployed, has been found to give an excellent spring temper. Nor is there any doubt that, carefully conducted, such tempering may be of the very best quality. A great deal, however, in this case depends upon the judgment of the operator, because very little variation in heating the steel or in the proportions of milk to water produces a wide variation in the degree of temper. If, on trial, the temper is too soft, the steel may be made hotter, or there may be more water added to the milk. If the steel was heated as hot as practicable without increasing the danger of burning it, more water must be added; while if the steel was made red-hot without being hot enough to cause the formation of clearly perceptible scale, the steel may be heated more. It is desirable, in all cases, but especially with a high grade of steel, to heat the steel not above a blood-red heat, although shear and spring steel may be, and often must be, made hotter, in order to cause it to harden when quenched in water. In former times the hardening by fire and water and tempering by the colour test were exclusively employed for hardening and tempering, except in cases where elasticity was the property sought to be imparted to the steel, and in this case a process termed blazing off (which will hereafter be treated of) was substituted for the colour test, and in those days the term "hardening" was understood to denote the process of heating to a cherry-red and cooling in cold water; this was sometimes further defined, if either of the terms "giving the steel all the water" or "hardened right out" was used to particularly specify that the steel was not to be extracted until reduced to the temperature of the water. The necessity for these terms arose from a practice that sometimes obtained, of withdrawing the steel from the water before it was quite cold, and many excellent hardeners and temperers there are, who at the present day withdraw the steel from the water when it has sufficient heat left in it to rapidly dry off the water adhering to it, the result being, it is claimed, to alter the degree of hardness to a practically imperceptible degree, but to add considerably to the strength of the hardened steel.

In those days tempering was understood to mean the second process, whose object was to modify, to a definite degree, by the colour test, the effects of the first hardening. Since the introduction of the other methods of hardening and tempering above referred to, the terms hardening and tempering have come to be used by many persons indiscriminately, and it is a fairly debateable question what process should be termed hardening and what tempering. First, then, any degree of hardness less than that obtainable in a given quality of steel, heated to the brightest degree without causing the change known to smiths as "burning the steel" to set in, must be a degree of temper, notwithstanding that it would have no representative colour under the colour test, because it is a degree of hardness less than the maximum.

In practice a toolsmith usually heats cast steel to what he terms a cherry-red; anybody, however, who has watched an ordinary blacksmith heating tools to harden will have observed that "cherry-red" practically includes all ranges of temperature between blood-red and a red verging upon deep yellow, the blacksmith being perfectly satisfied so long as the steel was not burned. The difference in the hardness obtainable by these two extremes of heating is not of practical importance in steels of fine grade; but in steels of inferior grade, as some spring and shear steel, it is so great that a blood-red will not appreciably harden, while a yellow-red will harden beyond the highest degree attainable under a colour test. The question arises then, shall a piece of steel possessing any of the degrees of hardness lying between that denoted by a yellow under the colour gauge and the highest attainable by giving the steel a maximum of heat (short of burning the steel) and "all the water," be termed hardened or tempered? Now, of these degrees of hardness we have no clear

conception, having no practical means of gauging it. If we give to a machinist a tool of a particular shape, he has such a clear idea of the hardness and strength it will possess when tempered to a colour, that he can determine how hard it can be made to perform a given duty, or about to what colour it must be made to leave it strong enough to withstand the strain due to a given duty. Or if we give him a piece of steel soft at one end and hard at the other end, the graduation proceeding uniformly from end to end, he can take a file, and after testing the hardness, mark upon the steel with tolerable accuracy the sections corresponding in hardness to a blue, a purple, a brown, and a straw colour, and would know of what hardness to make a tool that would cut the steel at any particular section not too hard to entirely resist cutting. This knowledge he has obtained from manipulations performed upon steel of all degrees of colour temper; but if we were to give him a piece of steel harder than any degree denoted by a colour, and yet not of maximum hardness, he would be dealing with an utterly unknown quantity.

"Tempering," applied to define the degrees of hardness denoted by the shades of colour ranging between the palest yellow and the deepest blue, conveys (in connection with a colour as, say, tempered to a straw colour) a clear idea of a definite and recognizable degree of hardness; but made to include a greater degree of hardness than is denotable under the colour test, it would cover in its meaning a number of unknown quantities which seriously impair, if not even destroy, its whole value. From this it appears that the word "tempered" (as applied to steel) should properly apply to all degrees of hardness denotable by colour in the colour test, and that "hardened" should include all degrees of hardness above that denoted by the palest yellow on the colour test. Under this interpretation, the meaning of the word will be extended to include all single processes which give degrees of hardness denotable by colours; hence the original meaning will be preserved to that extent. On the other hand, however, there is little doubt that the word was originally applied to the process because that process "tempered" or "modified" the degree of hardness of the steel, as indeed is proved by the fact that it was and is very often used interchangeably with the term "lowered"; thus, to lower to a blue was and is to temper to a blue; this is further attested by an old expression which is still in common use, viz., to "draw" the temper; thus, drawn to a blue implies that a piece of steel, "hardened right out" or "given all the water," has had its hardness reduced, or drawn, to the degree denoted by a blue colour.

We have, however, another consideration, in that steel given a definite degree of temper (corresponding to a colour under the colour test) by a single heating and quenching process has not been tempered in the sense that it has been lowered or suffered a reduction of hardness; on the contrary, it has received an increased degree of hardness. We may indeed stretch a point and claim that it has suffered a reduction of softness, but then temper is understood to mean, directly, a degree of hardness, because normal softness is in practice understood to be the condition as regards softness in which steel is supplied by the manufacturers. If from this condition it is rendered softer by softening processes, that is termed softening, while all degrees of hardness above that must come under the head of either hardened or tempered.

We have then to choose between including in the term "tempered" all processes which act to reduce the hardness of the steel to a degree recognizable under the colour test by a colour, or to confine its meaning to all processes by which the degree of hardness is modified, lowered, tempered, or lessened; and in view of the fact that the result reached and the object sought in either case is to obtain a definite degree of hardness comparable to that obtained under the colour test, the

former interpretation is undoubtedly the better. In any event it is an error to apply the term "tempered" to processes which, at one operation, leave the steel harder than any degree answerable to a colour in the colour test; while it has been shown that a process which reduces the hardness of the steel without bringing it down to a degree denoted by a colour in the colour test, should be termed hardening.

Heat Tests.—This matter would be considerably simplified if, instead of the colour, the degrees of temperature were specified; thus tempered to 460° F. (238° C.) would mean the same degree of hardness as a straw colour, and all the degrees of hardness above that would be specified in less degrees of temperature, and all degrees of softness down to a blue with a green tinge would be included in ranges of temperature up to 630° F. (332° C.). The degrees of softness below that, being indistinguishable by either a colour test or any other known indication save the ease with which it can be cut, would still remain unknown quantities or degrees. This plan would remove another technical objection to the colour test, which is, that the presence of a colour obtained on a piece of steel by subjecting it to heat is no evidence that the steel possesses any above its normal degree of hardness; for steel, wrought-iron, or even cast-iron, that has been softened to the lowest degree, will assume, on a polished surface, all the colours, providing that they are heated to the necessary temperature; hence the presence of colour is simply proof that the steel has been heated to a certain temperature, but by no means proof that it possesses temper, or indeed that the process of heating has in any way modified the degree of hardness or softness.

Tempering, when performed by a second operation, reducing the hardness obtained by a previous one, is dependent for its uniformity upon the uniformity of the first one; hence if a number of pieces of steel of the same grade be heated to an equal temperature and plunged in water until cooled, and subsequently tempered to the same shade of colour, they will all possess an equal degree of hardness; but if other pieces of steel of a different quality or grade (this may be further specified by saying "containing a different percentage of carbon") be subjected to precisely the same processes, leaving upon them the same temper colour, while this latter batch will be uniform in hardness, it will not possess the same degree of hardness as the pieces of the first batch: hence temper colour may be used as proof of equality in the degree of temper in pieces of the same steel, but is not indicative of any determinate and uniform degree of hardness. In tool hardening, this fact assumes but little practical difference, because for tools a special quality of steel termed tool steel is supplied, which will harden sufficiently to give accuracy to the colour test tempering, when heated to any degree of heat from blood-red to yellow-red, the difference of hardness in steel quenched, from either of these degrees of heat, being too small to be of practical moment in all tools comparatively inexpensive to make. In tools that are expensive, it is desirable to give the exact degree of temper which experiment has determined as the best. It will be noted that in the colour test the shades of yellow alone extend over a range of 70° F. of temperature, and tool users know that within these 70° F. lies a wide range of hardness. It is better, then, to adopt a tempering process that will determine with approximate accuracy the first heating temperature, such, for example, as by heating the article in some flux such as melted lead, melted salt, or melted glass, plunging it into a cooling mixture or liquid whose temperature can be maintained, by suitable means, somewhat equable, and drawing the temper in a bath maintained at the required thermometrical temperature. By this means, the steel used being a brand known for its uniformity, both the hardening and the tempering will have the greatest practically obtainable

degree of temper, and the tools will be hardened more answerably to the requirements of the duty than is obtainable under the colour test. This plan is indeed largely resorted to when large numbers of pieces require tempering; but if the articles are large, or tempering requires to be done piecemeal and at odd times, it will not pay, as a rule, to keep heating and tempering mixtures constantly ready upon the fire, and the open fire and colour gauge must be resorted to. It is under these latter conditions that the whole of the skill of the hardener and temperer is called into play, since, from the moment the steel is placed in the fire until it is cooled, all through to the temperature of the water, judgment and expertness are qualities absolutely essential to entire success.

Heating Steel.—In heating steel to harden it, there arise many considerations, the principal of which are as follows:—

As the steel becomes heated, it expands; if one part becomes hotter than another, it expands more, and the form of the steel undergoes the change necessary to accommodate this local expansion, and this alteration of shape becomes permanent. In work finished and fitted this is of very great consideration, and in the case of tools it often assumes sufficient importance to entirely destroy their value. If, then, an article has a thin side, it requires to be so manipulated in the fire that such side shall not become heated in advance of the rest of the body of the metal, or it will become locally distorted or warped, because, though there exist but little difference in the temperature of the various parts, the more solid parts are too strong to give way to permit the expansion; hence the latter is accommodated at the expense of form of the weakest part of the article. It does not follow, however, that the part having the smallest sectional area is the weakest when in the fire, unless it is as hot as the rest of the body. For example, suppose we have an eccentric ring, say $\frac{1}{2}$ in. thicker on one side than the other, and heat it midway between the thick and thin sides to a cherry-red; while those sides are barely red-hot, the part heated to cherry-red will be the weakest, and will give way most to accommodate the expansion, because the strength due to its sectional area has been more than compensated for by the reduction of strength due to its increased temperature. The necessity of heating an article according to its shape then becomes apparent, and it follows that the aim should be to heat the article evenly all over, taking care especially that the thin parts shall not get hot first. If, then, the steel is heated in the open fire, it may be necessary to take it from the fire occasionally, and cool it with water, and to so hold it in the fire that the thin part is least exposed to the heat. If the article is large enough, the thin part may be covered, or partially so, during the first of the heating by wet ashes. If, however, the article is of equal sectional area all over, it is necessary to so turn it in the fire as to heat it uniformly all over; and in either case care should be taken not to heat the steel too quickly, unless, indeed, it is desirable to leave the middle somewhat softer than the outside, so as to have the outside fully hardened and the inside somewhat soft, which will leave the steel stronger than if hardened equally all through. Sometimes the outside of an article is heated more than the inside, so as to modify the tendency to crack from the contraction during the quenching; for to whatever degree the article expands during the heating, it must contract during the cooling. Whether the heating be done in the open fire or in a heating mixture, it must be done uniformly, so that it may often be necessary to hold the article for a time with the thick part only in the melted lead or other heating material; but in this case it should not be held quite still, but raised and lowered gradually and continuously, to ensure even heating.

The size of an article will often be an important element for consideration in

heating it, because, by heating steel in the open fire, it becomes decarbonized; and it follows that, the smaller the article in sectional area, the more rapidly this decarbonization takes place. In large bodies of metal, the decarbonization due to a single heating is not sufficient to have much practical significance; but if a tool requires frequent renewal by forging, the constant reheating will seriously impair its value; and in any event it is an advantage to maintain the quality of the steel at its maximum.

Fuel for Heating.—To prevent decarbonization for ordinary work, charcoal instead of coal is sometimes used; and where hardening is not done continuously, it is a good practice, because a few pieces of charcoal can be thrown upon the fire and be ready for use at a few minutes' notice. Charcoal should be used for the heating for the forging as well as for that for the hardening. Green coal should never be used for heating the steel for the hardening, even if it is for the forging process; because, while the steel is being well forged, its quality is maintained, but afterwards the deterioration due to heating is much more rapid. A coke suitable for heating to harden should be made and always kept on hand. To obtain such a coke, make a large fire of small soft coal well wetted and banked up upon the fire, and with a round bar make holes for the blast to come through. When the gas is burnt out of the interior coal, and the outside is well caked, it may be broken up with a bar, so that the gas may be burned out of the outside, and then the blast may be stopped and the coke placed away ready for use at a moment's notice. Good blacksmiths always keep a store of this coke for use in taking welding heats as well as for hardening processes. It is desirable that the article be heated as quickly as possible, so as to avoid decarbonization as much as possible. If an article has a very weak part, it is necessary to avoid resting that part upon the coal or charcoal of the fire, otherwise the weight may bend it; and in heating long slender pieces they should bed evenly in the fire or furnace, or, when red-hot, the unsupported parts will sag. In taking such pieces from the fire, the object is to lift the edges vertically, so that the lifting shall not bend them; and this requires considerable skill, because it must be done quickly, or parts will get cooled and will warp, as well as not harden so much as the hotter parts.

Quenching.—We now come to the cooling or quenching, which requires as much skill as the heating, to prevent warping and cracking, and to straighten the article as much as possible during the cooling process. The cooling should be performed with a view to prevent the contraction of the metal from warping the weaker parts; and to aid this, those parts are sometimes made a little hotter than the more solid parts of the article, the extra heat required to be extracted compensating in some degree for the diminution of sectional area from which the heat must be extracted. Water for cooling must be kept clean, and in that case it becomes better from use. It may be kept heated to about 100° F. (38° C.), which will diminish the risk of having the article crack. Cracking occurs from the weaker parts having to give way to suit the contraction of other parts, and usually takes place in the sharp corners or necks of the articles, or through the weakest section; hence, in articles found to be liable to crack, such corners are made as rounded as possible. If the water is very cold, and the heat is hence extracted very rapidly from the outside, the liability to crack is increased; and in many cases the water is heated to nearly the boiling-point, so as to retard the extraction of the heat. Since, however, the hardening of the steel is due to the rapid extraction of its heat, increasing the temperature of the water diminishes the hardness of the steel, and it is necessary to counteract this effect as far as possible, which is done by adding salt to the water, the steel hardening more thoroughly in the saline mixture. To assist the hardening, various ingredients

are sometimes added to the water, such as fullers' earth, cyanide of potash, &c. All articles that are straight or of the proper form when leaving the fire should be dipped vertically, and lowered steadily into the water; and if of weak section or liable to crack or warp, they should be held, quite still, low down in the water until cooled quite through to the temperature of the water. If the article is taken from the water too soon, it will crack; and this is a common occurrence, the cracking often being accompanied by a sharp audible "click." Pieces of blade form should be dipped edgeways, the length of the article lying horizontally and the article lowered vertically and held quite still, because, by moving it laterally, the advancing side becomes cooled the quickest, and warping and cracking may ensue. Straight cylindrical pieces are dipped endwise and vertically. When, however, the dipping process is performed with a view to leave sufficient heat in the body of the article to lower or temper the part dipped, the method of procedure is slightly varied.

Since the hardening of steel consists of first heating and then rapidly extracting the heat, it follows that this latter part of the process may be performed otherwise than by the use of water—such, for example, as by placing the article in a current of cold air, or, if it is thin, by placing it between 2 cold iron plates. In these processes, however, the heat is not extracted quickly enough to give a great degree of hardness; hence, cold plates are rarely used, unless in cases where straightness and truth are of primary importance, and where straightening processes, to be applied after hardening, are inadmissible. When extreme hardness is required, it is not uncommon to quench the steel in mercury, which will harden to a much greater degree than water. To increase the efficiency of water, it is not unusual to boil it, which draws off the air contained in it; and there is no doubt that the superiority of water which has been long used for hardening is largely, if not altogether, due to its comparative freedom from air.

Degrees of Temper.—The considerations which determine the most desirable degree of hardness or temper are whether resistance to abrasion, capability of sustaining great pressure upon a fine edge, or elasticity, is the qualification sought to be imparted.

When elasticity is sought, tempering is absolutely necessary, because the degree of hardness accompanying elasticity is that represented in the colour test by the shades of blue. But when the requirements include the element of strength (as is always the case in cutting tools, and is sometimes the case in articles hardened to resist abrasion), then the degree of temper is modified to accommodate the strength, for steel hardened right out—that is, made as hard as fire (without burning it) and water will make it—is somewhat brittle and comparatively weak, but it resumes its normal strength as its normal softness is restored. Hence, if a cutting tool is of strong section, it is, in the best practice, hardened right out; but if it was found that the edge was, from excessive duty, liable to break off, it would be tempered to a straw colour, or still lower, even down to a blue if the requirements for strength demanded it. It is self-evident, however, that since the cutting capability of a tool is mainly dependent upon its degree of hardness above that of the material to be cut, the harder a tool can be made to stand the duty without breaking, the more and the better duty it will perform.

There is, it is true, a great difference of opinion with regard to the propriety of tempering many strong tools to a straw colour, especially in the case of planer tools for iron. Some of our most expert mechanics will temper such tools to a straw colour, while others, equally expert, will give them all the water—that is, harden them right out, and not lower the temper at all. There is among them all, however, a common practice of using the full degree of hardness in the tool when

the metal to be cut is hard, as is sometimes the case in even common unchilled castings, and since the harder the metal the more force it requires to sever it, it would seem that a tool strong enough for the hard metal should be sufficiently so for the soft metal. On the other hand, the tool is sometimes made less keen for the hard than for the soft metal, and the difference in the tool shape may give as much increase of strength as the increase of its hardness tends to weaken it.

Here let it be noted that the difference of opinion referred to is not in any way due to a difference in the steel, for, of two men operating the same tools in the same machine and upon similar work, one will simply harden and the other harden and temper the tools. Let he who would excel, however, never use tools of a lower temper than that which he finds will safely withstand the strain, and never rest satisfied until, under equal conditions, he can use tools as hard as the best of others engaged upon similar work, for in most cases it will be found that an advantage of shape is the cause of being able to use a tool of increased hardness.

Under equal conditions and under any given process, steel hardened with the outer or forged skin removed, will be harder, though tempered to the same colour, than if that skin remained, which appears an anomaly, since it is universally conceded that the forged surface is the closest-grained and most refined steel. An explanation, however, may be found in the probability that the forged skin, or scale, operates as a separate film or lining between the metal and the water, retarding the extraction of the heat from the steel; but, be this as it may, it must always be allowed for in tools in which the temper is drawn to give strength. Suppose, for example, the conditions require that a tool be filed to exact shape before being hardened, and that the proper temper for that class of tool, if hardened with the forged skin on, would be a pale straw, the temper with that skin off would require to be about a coffee-coloured brown; or if, in the first case, a deep reddish brown, then, in the second case, a clear reddish purple.

The surface of a piece of steel that is thoroughly hardened always appears white, provided that its surface was not covered with any substance during the heating process; and if any dark places or patches appear, it is an evidence that in those parts the steel is not so thoroughly hardened. For most colour tempering, except it be for springs subject to excessive duty in proportion to their size and shape, the presence of such dark spots upon good refined cast steel, such as tool steel, is not of sufficient importance to appreciably impair the value of the tempering. If shear steel, blister steel, machine steel, or any of the common qualities of steel are used, the whiteness of the surface is, however, a sure indication of the hardness of the steel, provided it was heated with its surfaces uncovered and quenched in water; but if the surface of any steel be coated with any of the substances sometimes used to prevent decarbonization, black or dark spots will not be an indication of local softness.

In large bodies of steel, the heat is not extracted from the internal metal sufficiently quickly to harden the interior to the same extent as the exterior. Furthermore, it is often necessary to have a free current of water in order to extract the heat sufficiently rapidly to harden the exterior, because the internal metal supplies heat to the external, thus partly counteracting the cooling effects of the water. In such cases, however, the coldest of water under pressure, and, if practicable, with salt added, may be employed.

In such sizes of steel as are used for cutting tools and instruments, it is not found that the internal metal is appreciably softer than the external, provided that the steel was heated equally all through.

In articles tempered to any degree not lower than a red purple under the

colour test, it is not found that removing the surface after hardening alters the temper, or, in other words, articles not tempered (by colour) to a lower degree than a very light purple, appear to possess their degree of temper equally all through the metal; hence, subsequent grinding and polishing does not impair the hardness, unless the operation should heat them. But in all the degrees of temper represented in the colour test, the blue purples and blue, removing the surface of the metal after tempering, will sensibly reduce the temper, the amount of the reduction depending upon the depth to which the surface was removed. The difference, however, will be found to be less in the case of refined cast-steel than when the quality of steel is that ordinarily used for springs. It is stated to have been found by experiment that the bare removal of the blue tint from a pendulum spring, by immersing it in weak acid, caused the chronometer to lose nearly one minute in each hour. It is also stated as a well-known fact, that such springs get stronger in a minute degree during the first 2 or 3 years they are used, from some atmospheric change; while springs plated with gold, silver, or nickel, remain constant, though the covering or plating may be so thin as not to compensate for the loss of the blue surface removed for the plating process. Be that, however, as it may, certain it is that the elasticity of tempered steel is rapidly affected by various conditions. Thus the springs of engine pistons partly lose their elasticity in the course of time, whether from the heat or from rusting it is hard to say. Springs operating under dry heat get harder, but whether this is not due to the crystallization of the metal is an open question.

It does not appear that the method of tempering affects the durability or elasticity, since the deterioration mentioned applies to springs tempered either on hot plates of iron, in sand, in heated fluxes, or by burning oil, or blazing, as it is termed.

Cracking and Splitting.—One of the most serious losses common to our tool and implement manufactories is that of the cracking and splitting of steel during the hardening process. Not only is the article or piece lost after having incurred the cost of its manufacture, but in many cases the completion of the machine of which it forms a part is arrested until the lost piece is replaced. In many cases this is done at increased expense, because the piece has to be made singly instead of with a number of others, involving as much setting of machine and adjustment of tools as would be required for a large number of pieces. Successful hardening and tempering is indeed, even under ordinary and unvarying conditions, considered and kept as a trade secret. Visitors are excluded from the hardening and tempering room. In some cases the method of heating, in other cases the material used for heating, in yet others the cooling mixtures, form the supposed secret. As a matter of fact, however, some of the very best tool manufacturers employ the simple open fire or furnace and water, and it is probable that with these two simple agents good cast-steel can be as successfully and properly hardened for any purpose as it can be under any other process, and the advantage gained by heating in fluxes consists in increased expedition and the necessity for a less expert manipulation.

The splitting or cracking of steel occurs during the cooling part of the hardening process, and is to be easily avoided even with the most unfavourable of steels, if the conditions of cooling are made to conform to the form and size of the article. The cooling is, in a majority of cases, performed by dipping the heated steel in water; and the manner in which the dipping is performed may be made at will to crack, warp, or straighten the article.

The instant the surface of a piece of red-hot steel enters the water, a rapid contraction of the submerged portion takes place, and unless this contraction is kept equalized to suit the shape of

the article, the side or part most contracted will bend hollow, causing the diametrically opposite metal to bend to accommodate the inner curve. Suppose, for example, we heat a piece of steel, 1 in. square and 12 in. long, to a red-heat, and dip it slowly in water, so that one side of the square will strike the surface flat and evenly, then that surface will contract while the diametrically opposite or upper surface will remain expanded; the lower face will curve to a concave, the upper one to a convex. If, then, such a bar were curved during the heating process, we may help to straighten it by dipping it slowly in the water with its convex side downward. If it was bent at one end only, we may dip at that end, first diagonally, and with the convex side downward. If, however, we dip it with the length lying either diagonally or horizontally, we are apt to warp it, no matter how quickly it may be dipped, and the reason is, in addition to the above, as follows:—Experiments have demonstrated that the greater part of the hardness of steel depends upon the quickness with which its temperature is reduced from about 500° F. (260° C.) to a few degrees below 500° F., and metal heated to 500° F. must be surrounded by a temperature which renders the existence of water under atmospheric pressure impossible; hence, so long as this temperature exists, the steel cannot be in contact with the water, or, in other words, the heat from the steel vaporizes the immediately surrounding water. The vapour thus formed penetrates the surrounding water and is condensed, and from this action there is surrounding the steel a film of vapour separating the water from the steel, which continues so long as the heat from the steel is sufficiently great to maintain that film against the pressure of the water and the power of the water which rushes towards the steel to fill the spaces left vacant by the condensation of the vapour as it meets a cooler temperature and condenses. The thickness of the vapour film depends mainly upon the temperature of the steel, but here another consideration claims attention. As the heated steel enters the water the under side is constantly meeting water at its normal temperature, while the upper side is surrounded by water that the steel has passed by, and, to a certain extent, raised the temperature of. Hence the vapour on the under side is the thinnest, because it is attacked with colder water and with greater force, because of the motion of the steel in dipping. Suppose, now, we were to plunge a piece of heated steel into water, and then slowly move it laterally, the side meeting the water would become the hardest, and would be apt to become concave in its length.

From these considerations we may perceive how important a matter the dipping is, especially when it is remembered that the expansion which accompanies the heating is a slow process compared to the contraction which accompanies the cooling (although their amounts are of course precisely equal), and that while unequal expansion can only warp the article, unequal contraction will in a great many, or indeed in most cases, cause it to crack or split.

After an article is dipped to the required depth, it should, if straightness is of importance, be held quite still until reduced to the temperature of the water, because if taken out before so reduced in temperature, it is especially apt to crack; and it is better to have a deep tank of water if the body of metal is great, so that the steel may be dipped slowly downwards, and become cooled sufficiently rapidly to harden without any lateral movement, except it be after the steel has lost its redness.

When a piece of steel requires to be hardened at one end only, the dipping must be performed with a view to make the graduation from the soft to the hard metal extend over a broad section of metal, for if the junction of the hardened with the soft metal is abrupt, the hardened end is apt to

break short off. The method of dipping, therefore, is in this case to plunge the end of the steel vertically into the water to a depth a little more than equal to the depth it requires hardening, and after holding it still there until it is black hot (that is, as soon as its redness is gone), dip it slowly a little deeper, and then raise it up to the amount of the increased dipping, and slowly immerse again.

When a piece of metal requires hardening and tempering at one part only, we may heat the steel back of the part to be tempered to redness, and dip the article so as to harden the required part, and leave sufficient heat in the contiguous metal to raise the temperature of the hardened part enough to temper it. This plan is always followed in the tempering of lathe and planer tools, flat drills, &c. If, however, the method of dipping is to hold the steel in the water at an even depth after the immersion, the temper colour will be very narrow, while if the steel is raised and lowered in the water, the colour-band will be broad.

Burning.—The whole value of the temper will be destroyed if the steel is made too hot and becomes what is known as "burned." As a general rule, unsatisfactory results will be found to have arisen from overheating the steel, for steel may have its quality impaired without giving evidence of being what is known as burned. If a piece of hardened tool steel shows brightness and crystalline formation under fracture, it has probably been burned; but if the fracture appears dull and even, it has not been burned.

Modifications of 'Dipping.—When a piece of work will be improved by having its exterior hardened and tempered, with the interior left softer, it may be heated in melted lead, the latter being covered with charcoal to prevent its oxidation. It is an excellent plan to heat the steel in some flux. The Waltham Watch Co. heat their hair-springs in melted glass. The Pratt & Whitney Co. heat their taps in a mixture of equal quantities of cyanide of potash and salt. The Morse Twist-Drill Co. use a similar mixture. The object of heating in these mixtures is to prevent the loss of carbon in the steel, which is of great consequence in small or slight articles.

When a tool requires to be tempered at and near the cutting edge only, and it is desirable to leave the other part or parts soft, the tempering is performed by heating the steel for some little distance back from the cutting edge, and then immersing the cutting edge and about half the rest of the steel, which is heated to red-heat, in the water until it is cold; then withdraw the tool, and brighten the surface which has been immersed by rubbing it with a piece of soft stone (such as a piece of worn-out grindstone) or a piece of coarse emery cloth, the object of brightening the surface being to cause the colours to show themselves distinctly, to indicate the state of the steel. The instant this operation has been performed, the brightened surface should be lightly brushed by switching the finger rapidly over it; for unless this is done, the colours appearing will be false colours. A piece of waste or other material may of course be used in place of the hand. The heat of that part of the tool which has not been immersed will become imparted to that portion which was hardened, and, by the deepening of the colours, denote the point of time at which it is necessary to again immerse the tool and quench it altogether cold.

The operation of the first dipping requires some little judgment and care; for if the tool is dipped a certain distance, and held in that position without being moved till the end dipped is cold, and the tempering process is proceeded with, the colours from yellow to green will appear in a narrow band, and it will be impossible to directly perceive when the cutting edge is at the exact shade of colour required; then, again, the breadth of metal of any one degree of colour will be so small that once grinding the tool will remove it and give us a cutting edge

having a different degree of temper or of hardness. The first dipping should be performed thus: Lower the tool vertically into the water to about one-third of the distance to which it is red-hot, hold it still for about sufficient time to cool the end immersed, then suddenly plunge it another third of the distance to which it is heated red, and withdraw it before it has had time to become more than half cooled. By this means the body of metal between the cutting edge and the part behind, which is still red-hot, will be sufficiently long to cause the variation in the temperature of the tool end to be extended in a broad band, so that the band of yellow will extend some little distance before it deepens into a red; hence it will be easy to ascertain when the precise degree of colour and of temper is obtained, when the tool may be entirely quenched. A further advantage to the credit of this plan of dipping is that the required degree of hardness will vary but very little in consequence of grinding the tool; and if the operation is carefully performed, the tool can be so tempered that, by the time the tool has lost the required degree of temper from being ground back, it will also require re-forging or re-forming. The distance a tool requires to be heated and dipped at the first dipping, and the distance to which the transient dipping should be performed, vary so much with the substance of the metal, that no rule can be given, more than to say that the heating should be to redness for a distance of about 3 times the diameter of the steel. A great deal of the cracking occurring during hardening arises from improper dipping. Cylindrical or square bar pieces should be dipped endwise. Blades should be dipped vertically and edgewise, with the length of the blade horizontal. The steel should be lowered vertically in the water, and for hardening should be held quite still near the bottom of the tank. The thick side should enter the water first. The water should be heated to prevent liability to crack; a difference of 40° or 50° F. makes no practical difference in the effectiveness of the quenching water, provided its temperature is at least 20° F. above freezing-point. Soft water is better for tempering than hard water, and the water improves by age, provided it is kept clean, which is an important element. Water at 200° F. (93° C.) will harden, and will reduce the liability of the work to crack, but it should contain 1 lb. salt per gal. in solution. (Joshua Rose, *Scient. Amer.*)

Annealing.—There are many ways of annealing steel: *e.g.* heating it to redness in the open or hollow fire, and then burying it in lime, in sand, in cast-iron borings, in dry sawdust, and by packing in carbon in an iron box and heating the whole to redness. This last process is the most effectual, provided the steel is not heated to excess. A layer of coarsely powdered wood charcoal is placed at the bottom of the box, then a layer of the steel, and so on until the box is nearly full, finishing with charcoal. The lid is luted with clay or loam; the whole is then placed in a furnace or hollow fire, and gradually heated to redness. Overheating is hurtful. It is seldom necessary to keep up the heat beyond the time when the contents of the box are uniformly heated, unless the steel should contain particles of hard impure iron, when it would be necessary to keep up the heat for several hours. When the whole has arrived at the proper temperature, the box is withdrawn from the fire and buried in hot or cold ashes to become quite cool, or left in the fire, and the fire allowed to cool down. The steel should be protected from air until it becomes cool, when it is taken out of the box, and is ready for the fitting or turning room. It is then very soft, and free from those hard bright spots which workmen call "pins." The surface of the steel will be as free from oxidation as before it was heated, and the greater portion of the charcoal will remain unconsumed, and can be used again. This mode of annealing prevents the steel from losing its quality; but it absorbs a small quantity of carbon,

which is favourable to the hardening process. Animal charcoal is sometimes used.

If time will not admit of a piece of steel being softened in a box with charcoal powder, it may be heated to cherry-redness in an open fire, then drawn out of the fire, and allowed to cool till the redness is not visible by daylight, but can be seen in a dark place, then plunged at this heat into cold water, and allowed to remain in the water until it becomes quite cool. When taken out of the water, it will be more uniform in temper than when it left the forge. This is a very expeditious way of annealing; but the steel will not be quite so soft as if it were enclosed in the iron box in contact with charcoal powder. Steel required to be annealed in such large quantities as to make it inconvenient, or the expense of enclosing it in boxes too great, may be heated in a charcoal fire completely enveloped and protected from the air. After the steel is heated to the proper temperature, the fire and the steel may be covered with pieces of plate iron, the whole then covered with cinder ashes, and the fire allowed to go out of its own accord. It will thus be protected until it is cold. Charcoal, especially when used as fuel in the open fire, is consumed with rapidity, and therefore very expensive. A cinder fire is less expensive; it is not so pure as charcoal, but purer than coal, and affords a very moderate heat. When the steel is at the proper heat it is taken out of the cinder fire and placed in an iron box containing coarsely powdered charcoal, which must completely envelop the steel; the box is covered up and luted with clay or loam, in order to exclude the air and preserve the charcoal for future use.

Cast-iron may be annealed in a similar manner. In the state it leaves the moulds it is always surrounded with a crust or coating, sometimes so hard that the best file will make no impression upon it, while the interior of the casting is soft and manageable. This hard crust is generally removed either by chipping with the cold chisel, or by grinding on a large grinding-stone turned by machinery. But when the shape of the casting is such that this crust cannot conveniently be so removed, annealing is the most economical process, as it makes the whole casting soft and much easier to work, but does not deprive it of its natural character. The heat requires to be kept up much longer than for steel, and the iron needs solid supports to keep it from bending or breaking by the heat. When annealed, it is more uniform in temper, consequently less liable to alter its figure by subsequent partial exposure to moderate heat. The outside is always somewhat harder than the inside, unless such processes be adopted as will extract the carbon from the former; but these processes deprive it of its natural character and make it in the condition of malleable iron, but without the fibre which is due to the hammering and rolling. Cast-iron cutlery is enclosed in boxes, and cemented with some substance containing oxygen, such as poor iron ores free from sulphur, scales from the smith's anvil, and various other absorbents of carbon. The boxes are luted as when annealing steel or case-hardening iron; they are afterwards placed in suitable furnaces, and the cast articles are kept in a state little short of fusion for 2 or 3 days, when they are found to possess considerable malleability, and can be readily bent and slightly forged. (Ede's *Management of Steel.*)

Recipes.—The following recipes for hardening, softening, tempering, and annealing are classified as nearly as possible according to the character of the article operated upon.

Case-hardening Wrought-iron.—(1) Wrought-iron is nearly pure decarbonized iron, and is not possessed of the property of hardening. But articles made of wrought-iron may be exteriorly converted into steel, and afterwards hardened. The process is called case-hardening, and only differs from cementation in being carried on for a shorter time; it is seldom necessary to convert the iron into steel more than

$\frac{1}{16}$ in. deep, unless where great stiffness as well as hardness is required. Case-hardened iron, for various purposes, is better than steel; it has the hardness and polish of steel externally, with a core of soft fibrous iron in the centre. Prussiate of potash renders iron nearly as hard as steel, by heating the iron to redness, sprinkling the potash finely powdered upon it, and then plunging the iron into pure cold water; but the hardness is confined to the surface, and only for articles not exposed to much wear can a sufficient coating of steel be obtained by this process. Greater and more uniform effect is produced by a perfectly tight box, and animal charcoal just sufficiently burnt to admit of being reduced to powder, in order that more of it may be got into the box with the articles; bones reduced to dust answer the purpose equally well. The box should be of plate iron, not less than $\frac{1}{8}$ to $\frac{1}{2}$ in. thick. The size and shape differ according to the articles operated upon. The box is furnished with an iron lid, with 2 holes pierced in it for drawing testing pieces out if required. The box may be strengthened against buckling by riveting a piece of iron about $\frac{3}{4}$ in. square inside the box about 1 in. from the top; this will also answer for the lid to rest upon, and prevent it from pressing upon the articles when expanded by the heat. Clay or loam put between this iron square and the lid makes a secure joint. Two holes are pierced in the box at opposite sides, just above the lid, for inserting 2 iron pins, and making the joint more secure. Upon a small scale, a good box may be made by welding a plug into one end of a piece of wrought-iron pipe, and using a loose plug for the opposite end; the loose plug being fastened into place with an iron pin passing through it and the pipe, and luted with clay. For a small article, a box may be formed of loam, gradually dried before it is exposed to a red heat. The articles being previously finished, except polishing, are put into the iron box in alternate layers with the animal carbon, commencing on the bottom of the box with carbon to the thickness of about $\frac{3}{4}$ in.; upon this a layer of the articles is placed, then another of carbon, about $\frac{1}{3}$ of the first, and so on till the box is nearly full, finishing with carbon about the thickness of the first layer, leaving room every way for the expansion of the articles by the heat, otherwise they will bend each other in the box. The packing completed, the lid is put on and the box is luted. The whole is now placed in a suitable furnace; the fire must not be urged, as the contents of the box require to be very gradually and uniformly heated to redness, and retained at this heat for a period answerable to the depth of steel required. In $\frac{1}{2}$ hour after the contents have arrived at the proper uniform temperature, the depth of steel will scarcely be the thickness of a sixpence; in an hour, about double the depth, and so on. To tell when the central articles arrive at the proper heat, a testing piece is withdrawn; if it be not sufficiently heated, the heating must be continued a little longer; after a reasonable time, another piece is withdrawn, and, if sufficiently hot, hardened in pure cold water; it can then be broken with the hammer, and the extent of the carbonization ascertained. Different kinds of iron absorb carbon unequally; consequently the testing pieces must be made of the same kind of iron as the articles. The more homogeneous the iron, the more equally it absorbs carbon; consequently, the less likely it will be to alter its figure in hardening. For testing pieces, plain pieces of the same kind of iron as the articles may be used. They require to be brightened, and are placed (at the time of the packing of the box) in the central part, in such a manner that they may be easily pulled out through the holes in the lid, either by a piece of iron wire attached, or by being made long enough to project through the holes, so that they may be gripped with pliers; the holes are luted, the same as other parts. When the articles are sufficiently converted, the box is drawn from the fire, the lid is taken off, and the contents are immersed

in pure cold water; taken out when cold, they are ready for polishing. The articles may (to prevent them from rusting) be dried by riddling in a sieve with dry sawdust, after which they are wiped with a greasy cloth. If the articles be immersed in oil instead of water, they will be much tougher but less hard, though sufficiently hard for some purposes. It is not necessary to immerse them at all direct from the box, as it answers equally well to allow them to remain in the box until cool, and then reheat them in an open fire, and immerse them separately. When the case-hardening is required to terminate at any particular part of an article, the part required soft may be bound with thin iron-wire, and cased with loam. This prevents the iron from absorbing carbon at that part. The loam requires to be gradually dried upon the article, previous to putting it into the box, otherwise it will crack. Another method is to shrink an iron ring or collar very tightly upon the part not requiring to be case-hardened; but this is not economical, especially when many articles require to be treated. To spare the trouble of shrinking a collar on and getting it off again, a collar somewhat larger in diameter than the article may be used, the space between being filled up with loam. When a collar is shrunk upon the article it has generally to be cut asunder to be taken off, and is useless in future; it may be got off by hammering, but this will damage the article if it has been previously finished, except polishing. If the article, after being cemented with the carbon, be immersed in water previous to taking the collar off, the collar will become hard, because it has absorbed carbon; consequently it will require to be ground on the grinding-stone before it can be cut off by the chisel, file, or turning tool. In some instances, when case-hardening is required to terminate at a particular part, it is more convenient and economical to postpone the finishing until after it has been cemented with carbon. Iron cemented with animal charcoal, however skilfully performed, is never as tenacious as iron cemented with wood charcoal; consequently, it is unfit for cutting tools, as it will not take a fine, firm edge, and, were it to pass through the process of forging and melting, it is questionable whether the material could produce such an effect. (Ede's *Management of Steel.*)

(2) Take some good charcoal (from oak the best); also some marble (carbonate of lime). Mix together, the marble having been broken small. Then lay the tool or other piece to be case-hardened in this compound in a covered box, and subject it to good and continuous heat. Result: a deep penetration of the carbon into the iron, and therefore a coating of steel. In other words, the outer cuticle has been converted into steel by the process of cementation.

(3) To economize in the more expensive materials for case-hardening cast, wrought, or malleable iron, and to harden only portions of the article in different degrees, if required, Gracie Roberts, of Brooklyn, makes use of an improved method. After polishing the surface, he glues to the portion to be case-hardened a coating of yellow prussiate of potash. A number of coats are given, according to the degree of case-hardening required. A cheaper material, or simply boneblack, is used where a slight effect only is required. When the glue is set hard, the article is packed in powdered charcoal, heated to redness in a quick fire, and maintained at that heat for ½ hour. Then it is hardened and tempered in the usual manner.

(4) Axle Arms.—Instead of using one large pan and plunging half-a-dozen arms into it, have a round conical box for each arm, made of old boiler plate, ⅜ in. thick, about 2 in. or 3 in. longer, and about 2½ in. larger in diameter inside than the arm. Into the box place sufficient animal charcoal to raise the collar of the axle-arm nearly flush with the top of the box, then surround the arm with the charcoal as far up as the collar, ramming it firmly down as you proceed, and finally cover the top of the

charcoal with fire-clay, taking care to well plaster the clay round the axle and the edge of the box. The furnace is a small reverberatory one, capable of holding 8 to 12 of these boxes at the same time. The boxes are allowed to remain in the furnace 1 to 2 hours, according to the size of the axles, &c.

(5) Common Prussiate of Potash Process.—Crush the potash to a powder, being careful that there are no lumps left in it, then heat the iron as hot as possible without causing it to scale; with a piece of rod iron, spoonshaped at the end, apply the prussiate of potash to the surface of the iron, rub it with the spoon end of the rod until it fuses and runs all over the article, which must then be placed in the fire again and slightly reheated, and then plunged into water, observing the rules given for immersing steel so as not to warp the article.

(6) Place the pieces to be hardened in an iron box, made airtight by having all its seams covered well with fireclay, filling the box in with bone-dust closely packed around the articles, or (what is better) with leather and hoofs cut into pieces about 1 in. in size, adding thin layers of salt in the proportion of about 4 lb. salt to 20 lb. of leather and 15 lb. of hoofs. In packing the articles in the box, be careful to so place them that when the hoofs, leather, &c., are burned away, and the pieces of iron in the box receive the weight of those above them, they will not be likely to bend from the pressure. When the articles are packed, and the box is ready to be closed with the lid, pour into it 1 gal. urine to the above quantities of leather, &c.; then fasten down the lid, and seal the seams outside well with clay. The box is then placed in a furnace for about 12 hours, when the articles are taken out and quickly immersed in water, care being taken to put them in the water endways, to avoid warping them. Articles to be case-hardened in the above manner should have pieces of sheet iron fitted in them in all parts where they are required to fit well and are difficult to bend when cold. Suppose, for instance, it is a quadrant for a link motion: fit into the slot where the die works a piece of sheet iron (say ¼ in. thick) at each end of the slot, and 2 other pieces at equidistant places in the slot, leaving on the pieces a projection to prevent them from falling through the slot. In packing the quadrant in the box, place it so that the sheet-iron pieces will have their projections uppermost; then, in taking the quadrant out of the box, handle it carefully, and the pieces of iron will remain where they were placed, and prevent the quadrant from warping in cooling or while in the box (from the pressure of the pieces of work placed above it). It is obvious, that the heavier pieces of work should be placed in the bottom of the box.

Cutters.—(1) If for a cold set, have it very stiff; round the corners slightly. The principle in tempering cutting-tools for striking on, is to avoid the "hard line": the temper should die away gradually. The system adopted with success is as follows:—1st. Always heat the tool a long way up. 2nd. Never dip in absolutely cold water. 3rd. Dip deep, and move the tool slightly up and down in the water. Half-round tools are most liable to fly; get it hot right up to head, and if there is not heat enough left to draw the temper in itself, get lump of white-hot iron to set the head on, or put head in fire.

(2) Quench in soft clay instead of water; it should be pretty stiff. Some things more susceptible to warping are done in this way. Plunge in sharp and straight.

(3) Get cutters just red-hot, and throw them into luke-warm water edgeways; they must be left in the water till all is cold, otherwise they will crack. If you cannot wait till the water gets cold, gently pour in cold water. If any warp, they can be put straight with a few blows over some hollow place when they are hot. In tempering them, do not trouble whether the teeth are sharp or round at bottom. By the above plan you will go over a

large quantity in a very short time; only be sure not to take them from the water till all is cold.

(4) Make the cutter of as low a red heat as it will harden at, and quench (flatways) in water slightly warmed. In forming the teeth, make the bottom round, not sharp, as they are more liable to crack at those points.

(5) Take a bucketful of clean water, and add 1 gill of vitriol; stir up well, and bottle for use. This will last for years if kept corked up: when using it, put your cutter on the top of a piece of sheet iron, and when properly red drop into the liquor. This, when taken out, will be as hard as flint. Blaze, and let down to a purple for cast-steel. This has never failed in 1 case out of 50.

(6) Drive a lump of iron into the hole in the centre, and after heating cutter and iron to the requisite redness for hardening, plunge both into the water. The heat in the iron keeps the steel round the hole hot sufficiently long to enable the steel to contract equally.

(7) "Carbonize" the fire by burning a lot of old scraps of leather, take a flat plate of iron, urge the bellows slowly to make this plate red-hot. Then lay upon the cutter, or saws, with another plate over this to throw the heat and carbon down until you can see it a pale red heat. Then take it off and slip it edgeways into about 1 qt. or more of oil. Do not use water. After being in about $\frac{1}{2}$ minute take it out and place it between 2 pieces of very flat hard wood, and squeeze it very tight in a vice; it will now be ready for use.

(8) Very gradually heat over a clear coke fire to a dull cherry-red, and then slide it, as it were, into the water quickly at an angle of 10° or 15°. Use water with the chill just taken off.

(9) Adopt some method of preventing the water having access to the hole and to the central part of the cutter when quenching. A good way would be to provide a rod of iron, say $\frac{3}{8}$ to $\frac{1}{2}$ in. diameter, screwed (tapped) for a distance of 2 in. at the end. First, put on a nut, then a broad washer, say $1\frac{1}{2}$ in., or even more, in diameter; next your soft cutter; then another broad washer, and lastly, a nut over that. Take plenty of time about heating the work, and have a good lot of fire ready blown-up; that is, avoid blowing the fire hot while the work is in it; but, on the contrary, have the fire already prepared, and let the work "soak," turning it over and over, till it is of an even temperature all over. If you prefer it, the piece of screwed rod need only be long enough to carry the work and the 2 nuts and washers, and you will then handle the whole with the tongs. Dip edgeways, and there will be no fear of flying in hardening. An incidental advantage is that it matters little if the cutter contracts in hardening, as sometimes is the case, for you can correct the hole by scraping or filing at your pleasure. Always avoid leaving much substance towards the middle of your cutters; $\frac{1}{16}$ to $\frac{1}{8}$ in. thick in the central web, held between a flat shoulder on one side and a well-fitted washer and set-screw on the other, is sufficient for cutters up to 3 in. or 4 in. diameter for milling wrought-iron. If you leave them thick, they will go to pieces, unless you specially provide against the water reaching them. Use a charcoal fire if you can get one.

(10) For cutters 3 in. and upwards in diameter, the hardening process is a hazardous one, and causes some anxiety. In the first place, the lowest temperature at which the steel will harden should be ascertained. If at a blood-red heat, so much the better. The cutter, when roughed out to near the size before the finishing cut is taken off, should be well annealed. This precaution is too often neglected—whether for large taps, lathe mandrels, or cutters, it will be found, after the annealing, that a degree of warpage has taken place, showing that the steel, though soft, was nevertheless in a state of tension, and this preliminary annealing greatly lessens the tendency to crack in the hardening. For a

cutter of 3 in. in diameter, a large clear fire of cinders should be used, great care being taken to heat the work uniformly. The cutter should be smeared over with a paste of soap and leather charcoal. This causes the finished cutting edges to come out bright and quite hard, after the quenching. Before hardening taps and drills, rub a piece of soap over them before heating, as no scale is then formed, and they come out clean after quenching. For large cutters, &c., in order to lessen the risk of cracking during the quenching, pour oil over the water to the thickness of a card.

Files.—(1) The point of a file, being thinner than the middle, is liable to become hot sooner, and attain a purple colour before the thickest part shows any degree of heat; to prevent which the heat must be applied gradually, by shifting the file backwards and forwards in front of (not over, because the smoke will colour it) a bright fire or furnace door, so as to keep the thickness. A piece of sheet-iron should be hung in front just above the file, to keep the glare of the fire from the operator's eyes, and by comparison from time to time with a new file (which should be at hand) he will be enabled to judge of the progress of the operation, and regulate the heat until the desired colour is obtained, when the file must be immediately plunged into water. Pale straw colour is low enough for most files, but no file should be brought lower than deep straw. (2) Cover with oil, and hold over the fire until the oil blazes, and as soon as the flame runs all over the file, plunge it in the water; or put in a moderate hot oven for ½ hour if large file; but if small, the former is better. (3) A mixture of tallow, hog's lard, and arsenic makes an excellent mixture for hardening files. The oil becomes thicker after being in use a week or two, and fresh oil is added each week, the thickest being taken out for giving a bright black to iron or steel.

Gravers.—Heat in charcoal dust (not too hot), and plunge into a box of wet yellow soap. This renders the end of the graver very hard and very tough.

Hammers.—(1) Drive piece of iron rod in eye to hold head by. Make full red hot, lay rod on edge of slack trough, harden the largest end, then turn small end in water, watch for temper in face, then the same to small end. When you have both ends right, keep turning them round in water until middle is about black-hot, then cool off. Do not dip deep. The colour will vary with different qualities of steel, and can only be determined by trial. With ordinary steel, from brown to blue will be about the thing. (2) A hammer weighing 1 lb. should be allowed 15 seconds to cool down before plunging, and then you will require nothing but clear water. Hammers weighing 2 lb., 3 lb., or 4 lb., should be allowed 30 seconds.

Lathe Mandrel.—(1) Have the water lukewarm, and a little soapsuds in it. Bring the mandrel to a cherry-red, catch by the end in tongs, and be sure to dip slowly and vertically to the bottom of the tub. If moved sideways, it will camber. (2) The risk of cracking steel when hardening is much reduced by surrounding the article, when in the fire, by shreds of leather, bone, &c., or by covering it with prussiate of potash as soon as it gets to a dull red heat; then it may be heated to the proper temperature for hardening. It is a very difficult thing to prevent the spindle from being bent and distorted. If hardened in water, it is almost sure to "warp," and, if the mandrel is a large one, it is not easy to harden it in oil. If it is of moderate size, heat it as above, with leather, &c., and at a good red heat; immerse it vertically in a mixture of oil and tallow.

Mill Bills.—(1) Get the point of the bill red-hot, put it on the ground to cool, try it with a saw file. If you cannot cut it, it is Mushet's steel. Treat as follows:—Get bright red, work out a little at a time. On no account hammer when getting cool, or they get

full of little cracks. Better keep heating as often as they lose their red appearance. The whole secret in working this steel lies in not hitting it unless red-hot. After you have got them to the right shape, which should be about $\frac{1}{8}$ in. thick at 1 in. from the end, get them bright red, and put them carefully on the ground to cool. This is all the tempering the steel requires. When cold, grind to an edge. If common cast-steel, you do not want to know anything about secrets or chemicals. All you have to do is to work it out at a dull red heat, hit it flatways when cooling as much as you like, but not edgeways; file or grind to an edge, get red-hot $\frac{3}{4}$ in. from the end, dip or cool in water with the chill taken off, grind bright, hold over a piece of red-hot iron till of a blue colour. (2) Salt, $\frac{1}{2}$ cup; saltpetre, $\frac{1}{2}$ oz.; pulverized alum, 1 teaspoonful; soft water, 1 gal. Do not heat above a cherry-red, nor draw to temper. (3) Put the body of the tool in the fire, leaving the 2 thin ends uncovered till the middle is red-hot. As soon as the middle is red-hot, pull back, and let the thin end just get a dull red heat. It must now be hammered edgeways first, and flatways last of all. It is best to hammer it on the flat part of the anvil, as drawing steel on the edge of the anvil, although a great deal quicker, makes it short in the grain, and always causes the tool to break in the thinnest place. Serve the other end the same, only repeat as soon as it loses its dull red colour. The lighter the blows in working steel, the tougher it is. The point should be quite as thin as a fitter's chipping chisel, only a little longer, then they will not require doing up so often. When the ends are drawn out, the middle will have lost its red heat. The ends can now be filed a little. To temper them, heat them in the flame of the fire, using great care. When a very dull red heat, cool in rain-water, with the chill taken off, about $\frac{3}{4}$ in. from the end, and let down to a blue; if it should be too brittle, a little lower. Serve the other end the same. Cool all over. Grind the edge rather blunt, and for the first few blows hit as lightly as possible. A little soapsuds or oil could be poured on the water, but water is the best. The secret is in working it at as low heat as possible, only keep on repeating very often, and to hit it edgeways as little as possible, but flatways as much as you like.

Mining Picks.—In the first place, a good charcoal fire is necessary; next, good steel, and then a good light hammer with a smooth-faced anvil. A pick should never be "upset," or hammered endwise, nor raised above a full red heat. The steel should be, moreover, heated as quickly as possible, as long exposure to heat—even if the heat is not in excess—injures its texture. Many blacksmiths find great difficulty in tempering picks, because they do not choose good steel. After being heated, the pick must be worked with care, special pains being taken, in drawing it out, to hammer on all sides alike, in one place as much as another, and on one side as much as another. When ready for hardening, it should be heated in the blaze of a charcoal fire until red hot, and then plunged into cold rain water, and kept there until it is nearly cold; but if kept too long in the water, or until it is quite cold, the corners are liable to fall off. Some blacksmiths use salt water; no salts of any kind should exist in the water, but the water should be cold; if the water is warm, and a little ice should be thrown in to chill it, the tempering will be all the better. Pure soft water for hardening will make a tougher pick, and one less liable to crack at the edges, than where salt water is used. An old miner who always sharpened the picks at the claim, and was quite expert at it, used to hold the pick end in the water exactly until a certain shade of colour appeared. Then he did not consider it properly tempered until the point was inserted in the ground and allowed to gradually cool. The last hammering of a pick should always be given on the flat sides, across close to the edges, and then up each side about an inch. By

doing so, the corners will be less liable to crack off.

Saws.—(1) After toothing comes hardening, the toothed plates being heated to a light cherry-red, and then plunged into a bath composed of whale-oil, tallow, rosin, and beeswax. The plates, after hardening, should be as brittle as glass. They are covered with scale, grease, and dirt, which is removed by scraping and scouring with sawdust. They come out buckled, and require to be flattened. This is done between heated dies brought together by hydraulic pressure. The dies are circular in form, horizontal in position, and about 5 to 6 ft. in diameter. They are enclosed in a furnace with an adjustable blast, and are revolved, to keep the temperature even. The proper colour for hand-saws is a blue, corresponding to spring temper.

(2) Dr. Hartmann recommends the addition of about 1 lb. rosin to the usual hardening mixture, consisting of $4\frac{3}{4}$ qt. train-oil, 2 lb. beef tallow, and $\frac{1}{4}$ lb. beeswax, as rendering it suitable for hardening some articles that do not harden sufficiently without it, although the proper amount of rosin can only be determined by experience, since excess of it may render the articles too hard and brittle. After use for some months, the mass loses its hardening power, and the trough must be thoroughly cleaned of it before fresh mixture is placed in it. He also recommends another mass, consisting of 95 qt. spermaceti oil, 20 lb. melted tallow, $4\frac{1}{2}$ qt. neat's-foot oil, 1 lb. pitch, and 3 lb. rosin. The pitch and rosin are melted together, the other ingredients added, and the mass is heated in an iron vessel until all the moisture is expelled, and the heated mass ignites from a burning splinter held upon it; the flame is thereupon immediately extinguished by means of a tightly-fitting cover. In employing either mixture for saw-blades, these, after being heated in a suitable furnace, are placed vertically in long troughs filled with the mixture, with the toothed edge, or that intended for the teeth, down, and as soon as they are sufficiently cooled, they are removed and wiped with leather until but a film of grease remains upon them, and are then placed flat over a coke fire until the coating ignites, by the burning of which their brittleness is diminished, and the requisite elasticity imparted. If they are to be very hard, but a small portion of the coating is allowed to burn off; but if softer, it may be allowed to burn until it goes out.

Springs.—(1) Harden right out, and then temper by flaring off in oil. If they are flat springs, a good way to harden them would be to get them red hot, and lay them on a flat iron surface, covered with water, quickly bringing another piece of flat iron (of about 7 lb. in weight) down on top of it. This will prevent them warping. If they are curved or bent, this cannot be done. If bent, put them into water (or oil, which is better than water for small springs) edgewise. To produce a nice spring temper, place them in a shallow sheet-iron dish, cover them with lard oil (this is important—mineral oils will not do), and hold them over the gas with a Bunsen flame until the whole of the oil has burned or flared away; then turn them out, and let them cool of themselves.

(2) First harden right out by making red hot, and cooling in water; then, to temper, have a bright, clear, arched fire, and move the spring to and fro in it until it is hot enough to scorch a stick or make sparks fly off a stick when rubbed along it, care being taken that it will do this all along the spring, and yet not be hot enough to set fire to the stick; then let it cool of itself.

(3) Whale-oil is used for tempering springs, which are first heated in the lead bath, then plunged in the oil, and blazed off in the fire.

(4) For long springs get a piece of 1-in. wrought-iron gas-pipe, put your spring inside, place the pipe in furnace. When hot enough, get hold of pipe with tongs, tip the pipe up over tank with oil or other tempering fluid in, and the spring will slip out into tank. If you have 2 or 3 pipes, you will temper over a gross per hour.

Taps and Dies.—(1) Rose says taps should be heated for hardening in charcoal fire, slowly to a cherry-red, and then dipped perpendicularly into clean water. The water should be made sufficiently warm to feel pleasant to the hand; for, if the water has not the cold chill taken off it, the taps are apt to crack along the flutes. The tap should be lowered perpendicularly in the water, even after it has disappeared below the surface; but in no case should it be moved sideways, or it will warp. It should not be taken out of the water until quite cold, or it will crack after it is taken from the water and during the cooling process. After the tap is hardened, it should be brightened along the flutes and on the plain part, and then lowered as follows:—A piece of tube, about half the length of the tap, and of about twice or three times its diameter, and having its thickness about the same, if possible, as the diameter of the tap, should be heated in the fire to an even cherry-redness, and then taken from the fire and placed in such a position that it is open to clear daylight, and not affected by the rays of light from the fire. The tap should be held in a pair of tongs, whose jaws have been well warmed; and a small piece of metal should be interposed between the jaws of the tongs and the sides of the square of the wrench-end of the tap, so that the tongs may not obstruct the square of the tap from receiving the heat from the tube. The tap and tongs should then be passed through the heated tube, so that the square end of the tap and the tongs only will be inside the tube. The tap should be slowly revolved while in this position, and when the tap has at that end become slightly heated, but not enough to draw the colour, the shank and threaded part of the tap should be slowly passed endways back and forth, and, while slowly revolving, through the centre of the tube, until the colour appears; if it assumes an even hue all over, proceed until a brown colour appears, then withdraw the tap from the tube, and quench it perpendicularly in warm water. If, however, the colour does not appear so quickly in any particular part, hold that part on the tube a little the longest, and if either end lowers too rapidly, cool it by a slight application of oil. The square end of the tap, on which the wrench fits, may be lowered to a deeper colour—as may also the shank of the tap—than the threaded part, which will leave them stronger and less liable to twist or break. By using the size of the tube here recommended it will be found that the tempering process will be performed, and the colours appear very slowly, so that there will be ample time to judge when the precise requisite degree of hardness has been reached. This plan is far superior to tempering in heated sand. Very long taps may be greased and heated preparatory to being hardened in molten lead—the object being to heat the outside of the tap evenly all over to a red heat, so rapidly that the inside metal of the tap is comparatively cool; hence, when the tap is hardened the outside only is hardened: and if the tap warps in the hardening, it can, after being tempered, be straightened—the soft metal of the centre of tap preventing it from breaking in the straightening, which should be performed with a leaden hammer and with the tap resting upon lead.

(2) Take the chill off the water, then get them to a cherry-red heat. Plunge the taps in on their ends. After they are cold, clean with a bit of stone or emery-cloth; then warm them till the spittle fries on them. Put some clean tallow on, then hold them over a clear fire till a light chestnut brown.

(3) The great difficulty in hardening tools is principally their liability to twist or get out of truth; secondly, cracking (especially if large) after hardening; thirdly, getting the right temper. First, carefully select your steel; let it be of the best cast, with a medium grain (a fine-grained steel will break when much less force is applied than a coarser-grained, and although it will take a keener edge, it will not resist the strain required by a tap or rimer). Next centre it, and turn off

the scale and soften. The object of softening after the scale is removed is to make the grain of the steel equal throughout; if it be softened with the scale on, it will generally cast. To soften, enclose the articles in a piece of gas-tube, filling up with wrought-iron turnings, and plugging the ends with clay, making the whole red-hot and allowing it to cool very slowly—*i.e.* leaving it in hot ashes all night. This method makes the steel very soft, and equalizes the grain. After softening, turn up the work, taking care not to bend or straighten it, should it have cast, as it probably will in the process of softening. The reason for this is, that if the steel be bent or hammered, the grain will be closer in one place than another, and heat has a great tendency to bring it back to its original position. The next thing after finishing your tool is to harden it: first, slightly heat it over a gas or other flame, and rub it all over with a mixture of Castile soap and lampblack. This is to prevent the edges from being burnt. The next is to get a thick iron pipe (2 in. diameter and $\frac{3}{4}$ in. bore). This is well filled up with taps or rimers and charcoal dust, the ends being closed with clay as before; this is placed in the furnace and occasionally turned, until it is one uniform heat of cherry-red, or on the outside a trifle hotter. It is then carefully removed from the fire, one end of the clay is knocked off, and the contents are allowed to drop perpendicularly into a solution of water, chloride of sodium, and nitrate of iron; this solution is kept at a temperature of 60° F. (15½° C.). The articles hardened should remain at least ¼ hour before being removed. This method of hardening may be summed up thus: make the steel of one grain throughout, prevent it from oxidizing whilst being heated, allow every part to heat at the same time, avoid bending while hot, and lastly, restore if possible by replacing the loss of carbon caused by heating.

Tools generally. — (1) Softening. (*a*) Heat your steel to dull redness, hold it in some dark or shady nook or corner until you can just see the least possible tinge of redness, then cool immediately in water at the ordinary temperature, and you will be able to file or turn it with very little difficulty. There are times when the delay of the ordinary process is extremely inconvenient—as in the filing of turning tools of a particular shape, re-annealing steel when the skin is taken off, &c., and then this mode answers admirably. (*b*) Make the steel red-hot, then put it in a heap of dry sawdust till cold, when it will be found to be quite soft. (*c*) Place a quantity of newly-burnt lime in a damp place, where it will fall in the form of flour; put it in an iron box. Heat the articles to dull red, clean off all scale, put in lime, and completely cover with lime; cover box over with iron lid, and leave until cold. The more lime and larger the box the better. Keep air-tight if possible.

(2) After being tempered, the volume of the tool is slightly increased, and consequently its specific gravity is decreased. As the expansion or increase of volume is so very slight, it is quite immaterial which is plunged in the liquid first; however, every moment the edge is kept out it is cooling, and the tempering may be rendered defective thereby. Mercury tempers the hardest, then water, then salt water, then oil of various kinds—as whale-oil. As oil cools the metal more slowly, it is not tempered so hard, but the tenacity is increased.

(3) It is said that the engravers and watchmakers of Germany harden their tools in sealing-wax. The tool is heated to whiteness and plunged into the wax, withdrawn after an instant and plunged in again, the process being repeated until the steel is too cold to enter the wax. The steel is said to become, after this process, almost as hard as the diamond, and when touched with a little oil or turpentine, the tools are excellent for engraving, and for piercing the hardest metals.

(4) Tools deeply dipped, and with the temperature let down slowly, are the best tempered. For instance, a carpen-

ter's chisel may be heated in a tube (covered with coke until the whole is at a red heat) until it is at a heat slightly more than blood-red; then lower vertically down to the bottom of a pailful of tepid water; when cold, take it out and polish it. Get a bolster, or large nut, heat it to whiteness, and traverse the chisel through and back until the surface has an orange or gold colour; cool out. Taps, dies, half-circular cutters, &c., so tempered, stand wear and tear much the best.

(5) The forging and tempering of iron or steel can be greatly enhanced, according to Blass, by dipping the metal, in whatever form, in fused salt. This dipping in salt is also well adapted for annealing steel without the oxidation of the surface. If the metal be rusted, it must be allowed to remain some time in the bath. Borax can with good effect be mixed with the salt. Metal "purified" by such an immersion is very susceptible to galvanic depositions, and can easily be coated with copper, zinc, tin, nickel, silver, &c. For iron in the spongy or powdered state, as obtained from the reduction of the ores, the salt bath is especially adapted, for it augments the combination of the particles by making their surfaces free from impurities. To prepare the bath for an application as here proposed, the salt must be fused in a puddling furnace, and the iron sponge, with the addition of a flux, be added in small quantities, so as not to vitrefy the salt. The iron is left in the furnace till the flux has combined with all the impurities, and formed a slag, whereupon the iron is taken out and forged together. While the iron is in the furnace, it should be constantly covered with the salt, so that oxidation be prevented. For the hardening of iron, the salt is fused in a convenient vessel and the object immersed, and from time to time a small quantity of potash ferrocyanide is added—1 lb. or 2 lb. per 100 lb. of iron. The articles, according to their thickness, are permitted to remain 5 to 30 min. in this bath, and are then plunged in water containing, in 100 parts, 1 of hydrochloric acid, 5 of wine vinegar, and 1 of salt. If the objects are to have a silver lustre, they should be immersed for a few minutes in a mixture of 3 parts wine vinegar and 1 of hydrochloric acid.

(6) Steel punches, or other small implements, particularly engraved dies, when, by accidental exposure to too great heat, they have become spoiled, or, as the blacksmith says, burned, may be restored by the following mixture: 2 oz. bichromate of potash, 1 oz. pure nitre, 1 oz. gum-aloes, 1 oz. gum-arabic, and 2 oz. rosin. The whole having been well powdered and mixed, the piece of steel is heated to low redness, and the powder sprinkled over it. It is then heated again to low redness, and cooled. This makes the piece very hard again. The amount of nitre may be doubled, and that of the rosin taken 10 times greater, to produce a higher temper.

(7) In tempering a tool for boring cylinders, turning rolls, or any large pieces of cast-iron, let it be as hard as water will make it, taking care not to heat it more than to cherry-red. In the second heating, after the tool is hardened, the first perceptible tint is a light straw-colour, which makes its appearance when the heat reaches 430° F. (221° C.). This gives the metal a maximum of hardness, with a certain amount of elasticity, fitting it for lancets, razors, and surgical instruments. At 470° F. (243° C.) a full yellow is produced, which is the temper employed for penknives, scalpels, and fine cutlery. The temperature of 490° F. (254° C.) gives a brownish-orange, suitable for shears and chisels used for cutting iron. At 510° F. (266° C.) the brownish-yellow becomes flecked with purple, the tint for pocket-knives. 520° F. (271° C.) gives a bluish purple, fit for table cutlery; while the different shades of blue from 530° to 570° F. (277°–299° C.) indicate a temper proper for watch-springs, sword-blades, saws, and instruments requiring great elasticity. Beyond this temperature the metal becomes too soft to be used for cutting instruments. The temper greatly depends on the

quantity of carbon that is in the steel. This the practical man soon finds out, and he tempers or draws down the tool accordingly. In Switzerland, razors, pocket-knives, &c., made from English cast-steel, are tempered by immersing the blades at a dark cherry-red into a bath composed of 4 parts finely powdered yellow rosin, 2 of fish-oil, to which is added, in a very hot state, 1 of melted tallow, and allowing them to cool perfectly; after which they are heated without wiping them, and hardened in water in the ordinary way. The blades hardened by this process are found to be more uniformly tempered than by any other, making it possible to produce an exceedingly fine cutting edge.

(8) By melting together about 1 gal. spermaceti oil, 2 lb. tallow, and ¼ lb. wax, a mixture is obtained very convenient for tempering any kind of steel articles of small size. Adding 1 lb. rosin, it is used for the tempering of larger articles. The addition of rosin must be made with care, for an excess of this material renders the steel too hard and brittle. After several months' use the mass loses its energy; it must then be wholly renewed, taking care to thoroughly cleanse the bottom of the tub which contained it. Another mixture, of which practice likewise has proved the efficacy, consists of 20 gal. spermaceti oil, 20 lb. tallow, 10 gal. ox-foot oil, 1 lb. pitch, and 3 lb. rosin. The pitch and rosin are melted together, then the 3 other materials are successively added, and the whole is heated in an iron pot till all the water is evaporated. This is ascertained when the mass takes fire at the approach of a burning chip of wood; the flame is put out by hermetically shutting the pot with a cover. The tempering is effected in both cases as follows:—Saw-blades, for instance, are heated in special ovens, and when they have reached the temperature, they are dipped in the mass contained in tubs arranged side by side. For a continuous manufacture a certain number of tubs are used, so as to allow the mass time for cooling during the progress of the operation. As soon as the blade is cooled, it is withdrawn from the bath and cleaned with a piece of leather, so that there remains still on it a thin layer of grease. It is then passed over a coke fire till the grease catches fire and burns with a clear smoke. In this way the blade acquires elasticity. If it is desired very hard, a part only of the grease is allowed to be burnt; the more softness is desired the more the burning is completed. For springs, the flame is left to burn itself out. If the objects are of various forms and sizes, the burning is repeated on the several parts till all are deemed equally tempered. The blades are finished by hammering and heating them again on a clear coke fire till they return to a straw-yellow hue. The coloration is then taken away by washing in dilute hydrochloric acid, and afterwards in plenty of water.

(9) Some mechanics attach much importance to a hardening pickle, but probably failure comes as often by injury in heating the article as by hardening and tempering. An evenly-distributed heat of the proper temperature is absolutely requisite to success, and this it is not always possible to assure by heating in an open fire. One portion of the article is liable to be overheated, while another portion is underheated; judging of the amount of heat by colour, is not always to be trusted; a dark corner or a cloudy day changes the conditions from a light shop and a sunny day sufficiently to make a great and telling difference in the amount of heat judged by sight.

A perfectly reliable method of heating for hardening is by means of the lead bath. It is an easy matter to keep in the shop a crucible or iron pot of lead to be used as occasion demands. The article to be heated for hardening will not suffer when in the lead bath, even if not closely washed, as is necessary at the open fire; the melted lead cannot pass to a degree of heat injurious to the steel. But one condition must be strictly observed — the lead must be pure and clean; it is best to buy the mercantile pig for this purpose.

In order to harden well, it is necessary to heat the article through and through. If the piece is of unusual thickness, as a tap or reamer of 3 in. or more in diameter, it is better to drill a hole through it from end to end, so that the heating can be even and the hardening be equal. A tap of 4 in. diameter broke squarely across in the hardening. It was of solid steel. The drilling of an inch hole from end to end was practised, and a large number of the same size taps were hardened without a failure. (*Scient. Amer.*)

(10) Firstly, the steel must only be heated to dark red, which is the temperature at which a film of soot burns off.

Secondly, the heated article must be carefully protected from oxidation; hence a flame rich in carbon must be used, and the immersion be done as quickly as possible, so as not to keep it long in the air.

Thirdly, water used for hardening must be free from alkalies and lime carbonate. (Reichel, *Zeit. f. Instrumentenkunde.*)

(11) A great many different articles require to be hardened. The first will doubtless be a cutting-tool of some kind. Take, for example, a set of tools for metal-turning — say, gravers, chisels, and parting-tools. The tools having been filed up and prepared, a clear fire at a small forge will be the best means of heating them. The tools are held by the tang in a pair of small forge-tongs, and the blade must be heated slowly until it is at low redness. Care must be taken not to overheat the steel, or its cutting properties will deteriorate, and in that case it will be perfectly useless as a cutting-tool. When the steel is made to the desired heat, it must be plunged into cold water, which will render it perfectly hard, and if it were used in this state, the point, or cutting-edge, would immediately break off. It depends a great deal upon the material that is to be turned what heat will be the best to make the tool before dipping or plunging it; and another plan, used in some cases, is to take the extreme chill off the water. The hardening having been finished in a satisfactory way, proceed to temper it and make it fit for use. The face of the end so hardened must be cleaned either with a piece of emery-paper or on a grindstone—either will do, as long as the part to be tempered is cleaned so that the colour can be seen when it appears. Having got all the tools that are to be tempered ready, make a piece of bar-iron about $\frac{3}{8}$ in. by $1\frac{1}{2}$ in. red-hot, and on it place the tools, with the hardened end extending beyond the heated surface, and in a short time it will be easily noticed that the bright part gradually changes colour—of course being deeper where it is nearest the iron. As soon as the cutting part gets to a straw-colour, it must be again dipped into water, to prevent its going deeper and becoming too soft for its purpose. There are also many different degrees to which cutting-tools for turning various substances should be what is termed "let down to." For example, a tool that is to be appropriated for turning steel, especially if it is not well softened, will require to be harder than one that is to be used for turning brass or gun-metal; therefore, if the latter is to be the material worked, leave the tool on the hot iron a little longer, until it becomes a darker straw-colour, or orange tint. Only practice will perfect any one in this most useful branch of mechanics. Any workman of experience can tell in a moment what temper will be required for the many different purposes the various tools are used for. Another way, which by men of practice is generally adopted, is to heat the tool, then dip it into water as far as necessary, and let down the temper with the heat left in the other end of the tool. The colour being obtained, the whole tool is cooled in the water, and the necessity for heating the iron is dispensed with. Assuming that a quantity of small articles are made, and ready to be hardened and tempered, great care must be taken not to overheat them; the best way to avoid this will be to build a small hollow fire, and

in this place an iron box, about 4 or 5 in. square, and open at the end. Make it red-hot, and on the lower side place the cutters in a row. The fire must be kept going, or the box will cool; they will soon get hot, subjected to the heat in the box. This not only makes a certainty of not burning the tools, but enables the operator to have a dozen at a time getting hot. When the whole lot are so hardened, the bar of hot iron will be again required. While this is getting hot, the faces of all the tools can be cleaned, and then placed in a row on the hot iron; and as they run down very quickly, being small, it is better to hold in the left hand a vessel of water, and with the right hand push off each tool as it assumes the required colour. By this means a number of articles may be soon effectually hardened and tempered. There are other means for effecting the same purpose. One of these is the blowpipe. Have a large piece of charcoal, in which make a hollow; there place the object to be heated, and blow the flame into the recess; it becomes a miniature oven, and all the heat of the flame is utilized. In making a spiral spring hot, prior to plunging, it will, if heated in an open fire, twist and bend all ways; the best way to avoid this is to get a piece of old gas-pipe, as near the size as convenient, and lay the spring in it, and then make the pipe hot. The spring will soon get sufficiently hot, and a regular heat will be the result, and it will be more likely to remain straight. The next thing will be to plunge it, but not in water. There are various opinions as to the best liquid to be used for this purpose; some prefer oil and water mixed. Another mode is to have a vessel containing a body of water, with about 1 in. of oil on the surface, so that the heated spring passes through the oil before it reaches the water. I give preference to a simple body of oil, and for a long thing like we have under consideration, a cylinder biscuit-tin will be found as good as anything to hold it. The spring being now hardened by the immersion in the oil, it must of course be tempered, and the best way to effect this is to blaze it—that is, after it has been placed in the oil, it should be taken out and held over the fire until the oil upon it catches light, and according to the degree of temper the spring is required to have, so long must the oil be allowed to flare. If a mild action is only wanted, it may be allowed to burn out, and be immediately dipped into water; experience alone can make any one proficient. The process of hardening a plain mandril is a piece of work with which great care should be again taken. Many people are under the impression that the mandril of a first-rate lathe should be all steel. This is an error, and it is only from want of knowledge that any one is impressed with this idea. To make a thoroughly good lathe the mandril must be composed of iron and steel. I am speaking now of a plain lathe; traversing mandrils are made of steel, but this is special. Taking, then, the plain mandril, the very best fagoted iron must be used, and round the part which is to form the bearing a thick ring of shear-steel must be welded. Cast steel will be of no use for this purpose, as it cannot be welded. The nose which eventually is to receive the chucks must be of iron. The mandril being fitted into its place as it must be, it will be ready for hardening, and the first thing to do will be to protect the nose from getting hot. To effect this, it must be covered with clay, bound on with thin binding-wire. It was at one time considered necessary for the heating of a mandril to have a hollow fire, but this idea has gradually died out. A mandril is a thing especially liable to break when heated and dipped into water; before dipping or plunging the mandril into the water, make a piece of iron hot, and stir the body of water with it. This is, to a certain extent, a safeguard; but nothing will make certain of its not breaking. The mandril must not be simply put into the water and taken out again, but moved about and allowed to remain until cold,

or nearly so. The traversing mandril is made of the very finest steel to be obtained, and as it has to be bored through, and is not of sufficient substance to admit of welding, the nose is in the solid with it. In hardening one of this description, a somewhat different process will have to be gone through. An experienced turner will detect at once, when turning a mandril, whether it is likely to require to be made to a greater or lesser heat; for instance, if the steel turns short and crumbly, so to speak, it will require less heat than if it will admit of a long shaving being taken, and is, in fact, of a much softer texture. A traversing mandril will be about 14 in. long, and will only require to be hardened where the fittings or bearings take place; that is, about 2 in. from the collar at the front, and 3½ in. at the small end, leaving 1 in. quite soft at the extreme end, where the guides are to be fitted. The first thing to do will be to protect the nose from being made hard; this can be done, as in the case of the plain mandril, with clay. There are differences of opinion as to whether the nose should have the screw cut upon it before or after it is hardened. One thing is sure: that if cut first, it will certainly require correcting afterwards; but if it can be kept perfectly soft, it is better to do it when the mandril is hardened. One reason why more care is required with this kind than with a plain mandril is that it is longer, and there are two bearings to harden instead of one, and the nose being of the same steel as the mandril itself, it has more risk of becoming hard. Having protected the nose, proceed with all care to harden. First make a clean fire, free from clinkers, and heat the end that has the collar on it first; when sufficiently hot, which will be a deep blood colour, plunge it into cold water. To keep it as straight as possible, the best plan is the following: before dipping, have a pail of clean water ready, and when the work is hot, take a stick and twist it round about in the pail, and so form a kind of diminutive whirlpool, the mandril being placed in the centre. The action of the water, in its circuitous course, tends to assist in keeping it in its original form; but take what steps you may, it is impossible to rely upon its being straight after it has been through such a course of treatment. The one end having turned out well—that is to say, hard—and not very much distorted, the other part may be done in precisely the same way, and when this is finished, it will be consoling to find the mandril is still intact, as it has often happened that, before going so far, it has broken. But here even the anxiety does not cease: it may be perfectly hard, not scaled nor broken, but, when placed between the centres of the lathe, it may be so crooked that it would be out of all character to try and grind it into straight line again. Mandrils of this kind were at one time always tempered so that they could be turned with a diamond point; but since the introduction of emery-wheels, this is avoided, and they are left perfectly hard, and ground true by means of a small emery-wheel running between two centres driven at great speed. But before grinding it true—that is, absolutely so—it must be brought as near as possibly so by other means; and it is here that the anxiety comes in. It may possibly be found when the spindle is placed between the centres, that it is bent in 2 directions; should this be the case, it is not at all an easy matter to correct it. It must, however, be done with the pane of a hammer, and the mandril itself placed upon a flat surface, and the blow from the hammer take effect upon the opposite side to where the error is; this is where the danger of breaking is, because a sudden or uneven jar is likely to make the mandril suddenly 2 pieces. Sometimes the steel, from various causes, will bear the blow upon the same side. The mandril must be held firmly in the left hand, and with the right hand the hammer is applied gently. Do not blow the fire fiercely, but let the material get gradually hot through, and then, when it is so, do not plunge

it in the water, and withdraw directly to see if it is cold; let it remain there till it is so. I have frequently heard a piece of steel crack some little time after it has been out of the water, but at the same time this may be no fault of the person who is hardening it—it is a thing that will, and unfortunately does, occur. Some authors direct that the nose of a mandril should be left as hard as possible. This is quite an error: let the nose of all such work be kept as soft as possible. In the hardening of small centre screws, and for such things as horizontal cutters and the like, many are broken from the fact of being made hard on the screw part; it will be clear that if the screw fits at all tight upon entering, it leaves the chance of the point being twisted off. To avoid this, do not harden it, and the way to prevent it is to have only sufficient water in a flat-bottom saucer, and when hot place the screw point downwards into it and move it about. Before the small body of water gets hot, remove it quickly into a greater body, and cool it. (J. H. Evans, *Eng. Mech.*)

Welding.—The following abstract of a paper by G. Newcombe, the secretary of the Cleveland Iron Trade Foremen's Association, will be found a valuable addition to the literature of the subject.

Conditions.—Newcombe calls attention to the ambiguity of language in which the conditions for an effective weld are often stated, and introduces extracts from some of the latest writers on the subject. Edward Williams, at the conclusion of a paper "On the Manufacture of Rails," read before the Iron and Steel Institute in September 1869, said welding was the one thing needful, and we should never lose sight of it. The chance of obtaining thorough welding would be much increased by not insisting on more toughness and fibre than is absolutely necessary to guard against so much brittleness as would bring about breakages of the rail in work. In the discussion on that paper, Sir William Armstrong said that in the manufacture of guns on the coil system, a perfect welding is just of as much importance as it is in the manufacture of rails. The conclusion arrived at, both at Elswick and Woolwich, was this, that in proportion as the iron has a steely character, so in proportion is it unfavourable for welding. The indication of its steely character was obtained by taking a specimen of iron heated to a certain point, and then plunging it into water. If its tensile strength was found to be increased beyond a certain limit, it was rejected as unfavourable for welding. The iron welds most perfectly which undergoes no increase of strength in the process of hardening. Williams, in reply to questions, defined good welding to be a combination of effects, an actual amalgamation of the surfaces, and soldering together by means of the cinder In proportion as there is more of the absolute contact and less of the soldering, so is welding good, and *vice versâ*. Where there is no contact of the actual metallic surfaces, and nothing but the soldering of the layers together by means of the cinder, it is poor welding; and it is the poorer the thicker the cinder. Where you have a large proportion of surface actually brought in contact with the layer next to it, then you have good welding. But perfect welding—that is, complete contact of surfaces, or anything at all approaching it—is impossible.

Mattieu Williams, in treating on lamination and blistering, says that when a blacksmith makes a weld in a common open fire, he throws sand on the surface to be joined, the object being to flux the scale—that is, to convert the oxide into fusible silicate. This being done, he brings the fluxed surfaces together, and by hammering forces out the liquid silicate, and thus brings clean surfaces of pure iron together, which at a proper heat unite perfectly. If he had a film of oxide between the surfaces it would prevent welding. Following up this principle, Mattieu Williams obtained from the potteries some "slip," or finely-ground flint used in glazing earthenware, mixed this with sufficient water to form a sort of paint

or whitewash, and with a whitewasher's brush painted it over the surface of the piles on both sides of each layer. He treated several piles of the finest quality of iron in this manner. They were rolled into boiler-plates, none of which showed any signs of lamination. He believes that by this means lamination may be effectually prevented.

At a meeting of the Iron and Steel Institute, Richard Howson, in a paper read before that society, "On Welding Iron," said that in order to obtain complete metallic contact the skill of the workman had to be exercised—1st, in heating the iron sufficiently; 2nd, in protecting the surface from oxidation by means of a flux; 3rd, in forming the surfaces in such a way that the flux has a means of escape when the ends are closed up under the hammer.

Having thus given a *résumé* of the latest theories on the subject, Newcombe examines them from a practical standpoint, to ascertain how far they are supported or contradicted by the most advanced practice of the day; and as Howson's views are of the most recent date, and may fairly be supposed to include much that had previously been said on the subject, he takes up the consideration of his conditions—first, on the necessity for proper heats to secure good welds.

Heating.—In point of importance, it rightly stands first, for if the primary cause of defective welding could be traced, its origin would in a majority of cases be found in bad heating.

There is no operation connected with smithing which requires more careful handling, or gives more anxiety to the smith, than the process of welding, for on the successful issue of one weld in the manufacture of a single article may depend either the success or loss of much labour and money. It may therefore repay us to examine with care the conditions to be observed in obtaining a good heat. In the first place, the fuel must be as free from metallic impurities as possible, especially sulphur, as it readily combines with iron, and with it forms sulphide of iron, which is naturally detrimental to the formation of a good weld; 2nd, by a proper construction of the hearth, and arrangement of twyer, to obtain the requisite chemical combination necessary for a proper combustion of the fuel for heating purposes. This is effected by placing the twyer about 4 in. below the level of the hearth for lighter kinds of work, and 6 to 8 in. for heavy kinds. But even with good fuel and the arrangement of twyer just spoken of, we may obtain two kinds of heat—viz., a carbonaceous (reducing) heat, or an oxidizing (destroying) heat; the carbonaceous is that which is required by the smith to reduce his iron to a welding condition, to obtain which he must maintain a constant supply of heated fuel between his twyer and the iron to be heated, and covering it likewise if the whole mass is to be heated. The chemical action which here takes place may be explained thus:—The oxygen of the air, after passing the twyer, comes in contact with the heated carbon in the fuel; chemical union then takes place; 1 part of the carbon combines with 2 of oxygen, forming carbonic acid; this, in passing through the heated fuel above it, takes up another part of carbon and forms carbonic oxide, which is composed of 2 parts carbon and 1 oxygen; and so long as this action can be maintained, we have a reducing heat suitable for bringing iron into the welding state with the formation of the least amount of oxide on the surfaces of the iron; and if we fail to obtain those conditions, and allow the fuel to become deficient in quantity between the twyer and the iron when it is in a semi-welding state, then we have a chemical action of a different kind, for the oxygen then being in excess, through a deficiency of carbon, readily combines with the iron, and forms a cinder or oxide of iron. This combination results in great loss of iron.

If the destructive effect of oxygen is so apparent on a small sample of iron, an approximate opinion may be formed of the great loss resulting from its action on large masses. In proportion as

we obtain heats, under either of the two conditions just named, so shall we get good or bad welding. If the oxidizing heat has acted on the iron, it leaves a film of cinder which is difficult to remove, and which prevents close metallic contact of the molecules needful to good welding; this is often apparent in examining large forgings, when turned and polished, that have been laid together or built up in slabs or piles. A dark horizontal line may be traced in the forging, which indicates the junctions of the slabs that in heating have been allowed to oxidize, perhaps through the furnace being too slow in heating, or through the admission of too much free oxygen. The oxide not being properly expelled while under the hammer, the result is a defective shaft, the weakness of which is soon made apparent if in performing its work it is subject to much torsion; whereas, if the mass had been heated in a full carbonaceous flame to that fine mellow or spongy condition so essential to a complete incorporation of the molecules, and which renders iron as nearly homogeneous as can be obtained under the piling system, no such thing would happen.

Fluxes.—He next examines the second section of the conditions just quoted as necessary to secure good welding—viz. protecting the surfaces from oxidation by means of a flux. The views advanced in this section of Howson's argument are so utterly at variance with the best practice of modern times, that Newcombe joins issue with him on this subject, as he is convinced that it is not necessary to use any flux in order to secure a perfect weld—that is, if the iron is comparatively free from carbon, and the proper conditions of heating have been observed. Large masses of scrap are welded up in forges, and smaller sections of iron in smithies, without any flux. Indeed, in the process, described by the author, of piling and rolling large armour-plates at Sheffield, and the manner adopted at Low Moor in manufacturing plates and bars, shows that no silica was used as a flux to assist the welding, other than that which the iron contained when it left the puddling furnace; yet the author admits that his samples were as nearly homogeneous as it is possible to get them without absolutely melting the iron. That welding may be effectively accomplished without the use of a flux, there are few workers in iron prepared to dispute; but as fluxes are used in welding, and chiefly by smiths, Newcombe inquires into the cause of their adoption.

The flux chiefly in use is sand; being abundantly found in nature, it is consequently cheap. It is composed of silicon and oxygen, and technically known as silica. It readily melts on being applied to hot iron; and it is this property, combined with its cheapness, that accounts for its general use. Why is it used by the smith? Because in joining 2 pieces of iron together different kinds of splicing or scarfing are adopted; those, or at least the most common in use, are of a pointed character, and they present an unequal thickness of iron to the action of the heat; and as the point of the scarf is farthest into the fire, and through its unequal thickness conducts the heat much quicker than the heel or thick part of the scarf, it consequently arrives in a welding state first, and, if the action of the heat was not checked, the point would be burnt away before the heel had arrived at a welding state. To prevent this, the smith throws on or dips the back of the point into the sand; the sand, on coming in contact with the heated iron, melts and absorbs so much of the heat of the part to which it is applied, and on melting becomes vitrified. This glassy silicate readily combines with the iron, and forms a covering to the part exposed to the heat, and being of a very refractory nature, it is some time before it is burnt off the iron. It thus protects the iron in its weak or exposed part, while the other or thicker part is absorbing the heat and arriving at the welding condition. It is sometimes used when the iron is on the anvil, but only when such iron is overheated, and will not bear hammering. A little sand thrown on absorbs the heat and

restores its cohesive power. The smith, in using sand, is always careful to keep it from the face of the scarf; he knows from experience that the cleaner he keeps the 2 surfaces to be welded the closer and more perfect will be the weld. This is the legitimate use of sand in welding; it is employed as a chemical agent to prevent waste of iron, and even in this capacity should be used as sparingly as possible, for its baneful effects are left behind on the forged articles, which, if they have to be either planed or turned, present on their surfaces a series of knotty or flinty points, which blunt the tool and are a source of much annoyance to the operator.

The use of sand is injurious to iron, and though it may be used as an agent to prevent waste of iron in some particular kinds of scarfing, it is not essential to sound welding. In support of this assertion, Newcombe refers to the welding of tires for railways and tubes for boilers; both these articles are continually under inspection for the purpose of detecting flaws or unsoundness, and they are subjected to continual tensile strain and shocks, which tend to develop any flaws or unsoundness; yet how few out of the many thousands in use give way at the weld, and they are invariably welded without any flux being used. Numerous other examples might be given of specialties of manufacture where the welding is done without any flux.

Selection of Iron.—Before closing this subject there is one matter nearly connected with welding which has not received that careful attention that it demands, and which future interests will require—the selecting of iron suitable for welding properly together; not that there is any difficulty in welding Cleveland iron, for it is remarkable for the excellence of that quality, yet there are few districts which produce iron that is more laminated. Perhaps this may, in a measure, be the result of the prosperity of the past few years, which has prevailed in the iron trade, when quantity and not quality was the great desideratum. In welding hard and soft irons together, the difficulty is to get a heat suitable to both, as it is difficult to define the exact temperature for iron in the welding state, for it differs materially according to the different degrees of quality of iron. The amount of heat which a hard pure iron would absorb before arriving at a proper viscous or pasty condition would be sufficient to destroy a soft impure iron by burning. Iron may be welded at different degrees of heat, varying in colour from a greasy yellow up to a white heat, and if heated beyond this point it becomes burnt, through not being fusible when in an uncombined state. Heat has great influence on iron in altering its condition. A high heat will change a fibrous to a crystalline iron, whilst a low welding heat will allow it to retain its fibrous character. Irons in a welding state possess great affinity or attraction for each other, and this is manifested in a greater or lesser degree according to uniformity of quality. If 2 pieces of iron are laid together in a welding condition, they readily stick to each other, and, if the surfaces are of moderate extent, it requires some force to pull them asunder. A striking proof of this attraction may be seen in any forge, in the piling of very large masses of scrap containing thousands of pieces, which are heated to a welding state, and then brought out of the furnace, and held in suspension by the middle, between the points of a pair of tongs, and though it may weigh 2 or 3 cwt. there is no difficulty in transmitting it from the furnace to the anvil, during which time the particles composing the mass are held together by atomic attraction, but some mechanical force is necessary to bring the particles into closer metallic contact. The difficulty is not so great in welding hard and soft irons together as in keeping them together after they are welded. In a sample containing 5 different kinds of iron, of varying degrees of quality, the welds, so far as can be judged from appearance, seem to be perfect, yet if this sample had much

work put on it, if it were upset under the steam-hammer, the harder knots would separate from the softer, their structural forms are so different. The fine crystalline form of the Low Moor iron cannot be thoroughly incorporated with the open molecular structure of the common Cleveland. Much of the defective welding found in Cleveland iron is due to this cause: we find on examination a layer of crystal and another of fibre in regular succession throughout the commoner kinds of iron. A low heat is adopted in its manufacture, purposely to retain its fibrous character; the result is the lamination spoken of. This evil is not confined to the manufacture of bars only; the rail trade has suffered from the same cause. Welding, properly performed, is neither a soldering nor gluing process. Neither of those words is applicable to the process. It is possible to get a near approach to complete metallic contact by welding; but as the conditions are so varied by reason of the different chemical combinations in iron, it is impossible, in the present state of metallurgical science, to lay down any fixed rules; therefore, the skill and observation of the workman must supply this want, and be constantly directed to those affinities and combinations which are constantly taking place in all metallurgical operations, under fixed though perhaps undefined laws, which govern the results, and give good or bad work in proportion to the extent in which they are regarded or neglected. (*Eng. Mech.*)

Nature of Welding.—In the address of Jordan, President of the Société des Ingénieurs, delivered at the annual meeting of that society in Paris, a novel explanation of the welding of iron is offered. Jordan says that welding is a phenomenon exactly similar to the regelation of water, the phenomena of regelation being these, that if 2 or more pieces of ice at a temperature not lower than their melting-point, or preferably at a temperature much higher than their melting-point, be pressed together, the liquid water adhering to their melting surface becomes solid at the places of contact, and thus the 2 pieces are refrozen into one. Jordan very aptly illustrates the phenomena of regelation by the making of a snowball, telling us that this may be done when snow is at a temperature not lower than 32° F. (0° C.), *i.e.* the freezing-point of water. Every man will remember that when the snow is very dry, and the temperature of the air below the freezing-point, the snow-flakes will not cohere without the aid of much pressure and warmth from the hand, but that with sloppy snow during a thaw, one can make a hard ice snowball with ease. Jordan compares the making of the snowball with the welding of the iron ball, maintains that the processes are identical, and applies Sir W. Thomson's explanation of regelation to the cases of iron and platinum welding.

It appears to Prof. Mattieu Williams that the conditions of solidification in the 2 cases are not only by no means alike, but are diametrically opposite, the welding of both iron and platinum being effected at a temperature considerably below their melting-point, while the primary condition for the cohesion of 2 pieces of ice by regelation is that they shall be exposed to a temperature above, or at least not below, their melting-point. In order that regelation should be analogous to welding, it should take place at a temperature far below the freezing-point. Now, it is well known that under such circumstances regelation does not and cannot occur, and therefore it differs essentially and primarily from welding.

If it had been discovered that 2 or more pieces of iron, while in a furnace, raised above their melting-point and steaming into fusion, would cohere when pressed together, and that this cohesion resulted from the solidification of their liquid surfaces, in spite of the melting heat of the furnace, we should have an analogy with the regelation of melting ice, and Jordan's conclusions would be justified. Regelation means the resolidifying of a liquid, or a special cohesion in spite of liquidity; welding means a

special cohesion in spite of solidity or apparent solidity. If Jordan had described them as examples of curiously opposite actions, the comparison would have been more nearly correct. We might plausibly assume that, while the pressing together of 2 pieces of wet ice produces a solidification of the surface liquid, the pressing together of 2 pieces of heated iron has the opposite effect of momentarily liquefying the surfaces of contact, and thereby soldering them together. The plausibility of this explanation is increased by the fact that pressure develops heat, and thus the welding heat might, at the surface of contact, be momentarily raised to the fusing-point, and then, on the removal of the pressure, this liquid film might solidify and thus produce the welding cohesion. But even this theory is, in Williams's opinion, too learned. A far simpler explanation may be found, and we must never forget that when 2 or more explanations equally fit a given set of facts, the simpler is the better, and usually the true one.

In order to find a true analogy to welding, we need go no further than the vulgar "sticking together" of two pieces of cobblers' wax, pitch, putty, or clay. These are in a viscous or semi-fluid condition, and they cohere by an action similar to the transfusion or intermingling and uniting of 2 liquids. Iron and platinum pass through a viscous or pasty stage on their way from the solid to the liquid states, and the temperature at which this pasty condition occurs is the welding heat. Other metals are not weldable, because they pass too suddenly from the solid to the liquid condition. Ice, although it fuses so slowly, in consequence of the great amount of heat rendered latent in the act of fusion, passes at once from the state of a brittle crystalline solid to that of a perfect liquid. It passes through no intermediate pasty stage, and therefore is not weldable, or does not cohere like iron, &c., at a temperature below its fusing-point.

It is usual to cite only iron and platinum, or iron, platinum, and gold as weldable substances, but this is not correct. Lead should be included as a weldable metal. The two halves of a newly-cut leaden bullet may be made to reunite by pressure, even when quite cold. This is obviously due to the softness or viscosity of this metal. Outside of the metals there is a multitude of weldable substances. Glass is a typical example of these. Its weldability depends upon the viscosity it assumes at a bright-red heat, and the glass-maker largely uses this property. When he attaches the handle to a claret-jug, or joins the stem of a wine-glass to its cup, he performs a true welding process.

The chief practical difficulty in welding iron arises from the fact that at the welding heat it is liable to oxidation, and the oxide of iron is not viscous like the metallic iron. To remedy this oxidation, the workman uses sand, which combines with the oxide and forms a fusible silicate. If he is a good workman, he does not depend upon the solidification of this film of silicate, as the adhesion thus obtained would be really a soldering with brittle glass, and such work would readily separate when subject to vibratory violence. He therefore beats or squeezes the surfaces together with sufficient force to drive out between them all the liquid silicate, and thus he secures a true annealing or actual union of pure metallic surfaces.

Cast iron or steel containing more than 2 per cent. of carbon cannot be welded, because the compound of iron with so much carbon is much more fusible than pure iron, or than steel with less carbon, and it runs more suddenly or directly from the solid state into that of a liquid, and hence presents no workable range of weldable viscosity. (Mattieu Williams, *Iron.*)

Recipes.— Steel. — (1) An excellent composition for welding cast-steel is prepared by boiling together 16 parts borax and 1 of sal-ammoniac over a slow fire for 1 hour. When cold, grind it to powder. The steel must then be made as hot as it will conveniently bear, and the composition used the same as sand.

(2) There is one point in welding steel which cannot be too strongly insisted upon, and that is that the pieces, after having been brought to welding-point, should not be struck heavily with the hammer, but only tapped lightly at first until they have begun to weld; after that, the sledge or steam hammer may be used with perfect freedom. Another important thing in welding steel is the heat. While it is impossible to give any specific rules on this point, the general rule, which will be found to hold good in all cases, is not to heat the steel any higher than is absolutely necessary to effect a weld—the higher the steel is in carbon the lower the heat at which it ought to be worked, hence necessitating heavier hammers—and next, not to finish the operation at too low a temperature. It will be best to work the steel as rapidly as possible, reheat as often as required to prevent working or finishing cold, and anneal immediately after welding the whole piece—not only the immediate vicinity—containing a weld. The annealing heat should always be higher than that at which the piece was finished. Another source of danger to the homogeneity of the finished product is to be found in cold-straightening. The presses in many mills are so constructed as to exert absolute shearing stresses, and are apt to do more harm than any subsequent service can do. Cold-straightening ought to be done at black heat, and the local effects of the press be modified by distribution over a large area. This can be accomplished by the use of broad oak wedges or the insertion of pieces of plank. Generally, plates, angles, beams, &c., have of necessity to undergo more or less hammering in the course of construction, and as this produces effects comparable to punching and shearing, though in a much less degree, it becomes necessary, in steel construction, to modify these effects in the same way by protecting the metal surface with wood and substituting heavy wooden mallets for sledges. In time, the working of steel in every stage requires care—and, above all, intelligence—and the men engaged in it must be impressed with the necessity for careful manipulation and rational treatment. Undoubtedly the steel must possess the proper qualities for structural purposes in the first place, but then it must also be properly treated subsequently if it is to bring those qualities into the finished structure. (A. Hill.)

(3) Shear and double-shear steel are easily welded, and the latter will answer almost all the purposes of cast-steel. Cast-steel, however, is more difficult to weld, but it can be done by practice. Care must be taken not to heat too hot, or it will fall to pieces under the hammer. Use powdered borax as a flux.

(4) A mass of ingredients is sold for the purpose of welding cast-steel, but the simplest and best method is, according to the *Revue Industrielle*, the one employed by Fiala, of Prague, Bohemia. He uses pulverized white marble for the purpose. The 2 pieces to be welded together are heated, and, after rolling in marble dust, are promptly joined together, and subjected to a good hammering.

(5) Cast-steel can be, and is, successfully welded; but there is greater difficulty in the accomplishment of the process than with other kinds of steel, and it requires a practical hand to make a good job. The precautions necessary to ensure success are as follows:—Keep it from the air while being heated; heat as quickly as possible; don't make it too hot, or it will burn, and break in pieces when hammered—for cast-steel requires a low welding-heat; strike lightly at first, and increase to heavy blows; don't use coals, for they contain sulphur, and will give the surface of the steel a coating of sulphide of iron; but use coke, or what smiths term "breeze," that is, coal well burnt and the cinders washed. Use the following flux:—Borax ¼ lb., washing potash ¼ lb., and a small quantity of white glass, powdered; melt together, and when cold, pound it. This flux will dissolve the oxide that forms. Apply some before putting in the fire, to protect

surface of work from oxide, and apply more at your own discretion. If wanted to weld cast-steel to iron, the iron will require a greater heat than the steel.

(6) The sand usually employed must be discarded, and borax employed in its stead. Some of the cast-steels require a still more fusible flux than even borax, and sal-ammoniac is mingled with it; 1 of sal-ammoniac to 15 or 20 of borax is sufficient. The best mode of using borax is to put it in an iron kettle or ladle over the fire, and heat it until it discontinues to boil up, when cold, reduce it to a powder. When the steel is somewhat heated, the powdered borax is applied, and when again inserted in the fire, the heat is raised as high as the steel will bear without injury. When at the point of fusion, on to the anvil with it quickly; hit it lightly, very lightly, at first, till it begins to adhere, and increase the force of the blows by degrees. If the joint is not satisfactory, try a second heat with another application of the borax.

(7) Put ¼ lb. saltpetre, and ¼ lb. oil of vitriol, in 2 gal. water, heat ends of steel red-hot, and cool them in the mixture before welding. Make a longer scarf than for iron, using nothing but sand while heating; but be sure to get sand with a glassy grain, and free from sulphur. Heat high above the iron, roll your heats well in the sand, keeping plenty on the off side, for it melts and runs below, and forms a capital flux. Be careful not to heat too high. Don't brush your heats, or you will take away the flux; if there be any dirt on them just tip it off, and you will have a good solid weld. If you don't get it solid with first heat, you can take another heat over all, using sand the same as at first.

(8) The cheapest flux is a piece of soft clay. First get your heats to a cherry-red in a clear fire; then just dip in the clay. You will find it form a thin coat on the scarf; then put your heats in the fire, and when you see the clay run off the point of the scarf, it is right to weld; but be careful not to get your heats too hot behind the scarf. In shutting your heats, tap them lightly till you feel them begin to stick, then you can have your hammers down on it.

(9) There are so many grades or tempers of cast-steel now in use (from steel rails to surgical instruments) that there is a great difficulty in understanding what is meant by cast-steel. The old system of steel-making was the converted or cemented process; the converted bars were welded once or twice, then called single or double shear-steel, according to treatment received. In the Huntsman or crucible process, the converted bars were broken up into small pieces and charged into crucibles along with oxide of manganese, &c., and when melted, cast into ingots, hence the term cast, to distinguish from shear-steel. We have 3 methods by which cast-steel is produced, *i.e.* Bessemer, Siemens, and Huntsman (crucible) processes, and the various qualities and tempers manufactured by these are legion. Some of these steels will weld without any difficulty, and some with only the greatest difficulty; some kinds will harden very hard when plunged into water at a red heat, and others, when subject to the same treatment, will bend over and over without showing any signs of a fracture, the sudden cooling having made no perceptible difference; yet both are cast-steel, and probably may have been made from the same process. Cast-steel rails are sold at about 9*l.* per ton, cast-steel for tools at 60*l.* to 140*l.* per ton.

(10) Two points must be taken into consideration chiefly in effecting the welding of steel: it is necessary to render the film of oxidized iron on the surfaces to be united by welding as fluid as possible, and some means must be found to restore to the steel the carbon eliminated during the process of heating to the welding temperature. According to the *Revue Industrielle*, Rust considers boric acid the most effectual in performing the former, and ferrocyanide of potassium in doing the latter. Rust considers the functions of the ferrocyanide to be also to restore to

the steel nitrogen, upon which he looks as an important constituent of the metal. In 1850, a workman of Mulhouse, Alsace, sold the following recipe for a welding compound: 65 parts borax, 20 of sal-ammoniac, 10 of potassium ferrocyanide, and 5 of colophony. Rust changed it as follows:—61 of borax, 17¼ of sal-ammoniac, 16¾ of ferrocyanide, and 5 of colophony. He states that, with the aid of this compound, welding may be accomplished at a yellow-red, or at a temperature between the yellow-red and white, and that no treatment is necessary after welding. The borax and sal-ammoniac are powdered, mixed, and are slowly heated until they melt. Heating is continued until the strong odour of ammonia ceases almost entirely, a small quantity of water being added to make up for that lost by evaporation. The powdered ferrocyanide is then added, together with the colophony, and the heating is continued until a slight smell of cyanogen is noticed. The mixture is allowed to cool by spreading it out in a thin layer. During the process given, boric acid and chloride of sodium are formed, ammonia being expelled. The same product may therefore be obtained by mixing 41·5 parts boric acid, 35 of dry sodium chloride (salt), 15·5 to 26·7 of potassium ferrocyanide, 7·6 of colophony, and 3 to 5 of dry soda carbonate. The only trouble with this mixture, which gives the same results, is that it decomposes easily, unless it is kept in a dry place.

Broken Spring Plate.—Get the length, and then take the part of broken plate which is easiest to handle, and upset it suitable for welding. Make a piece of iron ⅜ in. wide, quite thin at one edge, leaving the other about ⅜ in. thick, something like a razor-blade. Take a welding heat on the part that has been upset, and weld the iron across, having the thick end on the point of the plate. Scarf it for welding, upset the other part of plate, and scarf it so that when welding the piece of iron comes between the two steels. In the first heat—it cannot be done in one—don't strike too hard at first, and thin down any thick edges of the scarfs. Take a second heat, and the result will be, in the hands of an average smith, a good sound weld. If the steel is at all fiery, do not attempt to weld it. Should there be a hole near the broken place, showing, on being heated, any sign of a flaw, make a new plate. The piece of iron welded between facilitates the welding, and also makes up for the length lost in jumping.

Cast-iron.—The Chinese process of welding cracked iron wares by cementing them with molten iron is thus described:—In the case, for example, of a cast-iron pan requiring such treatment, the operator commences by breaking the edges of the fracture slightly with a hammer, so as to enlarge the fissures, after which the fractured parts are placed and held in their natural positions by means of wooden braces; the pan being ready, crucibles made of clay are laid in charcoal and ignited in a small portable sheet-iron furnace, with bellows working horizontally. As soon as the pieces of cast-iron with which the crucibles were charged are fused, the metal is poured on a layer of partly charred husk of rough rice, previously spread on a thickly-doubled cloth, the object of this being to prevent the sudden cooling and hardening of the liquid metal. While in the liquid state, it is quickly conveyed to the fractured part under the vessel, and forced with a jerk into the enlarged fissures, while a paper rubber is passed over the obtruding liquid inside of the vessel, making a neat, strong, substantial, and in every respect thorough operation.

LACQUERS AND LACQUERING.—These terms, as generally used, cover such a wide ground, that no accurate definition can be given. The subject may be conveniently divided into the following sections.

Brass Lacquers.—(1) Seed-lac, dragon's blood, annatto, and gamboge, each 4 oz.; saffron, 1 oz.; wine spirit, 10 pints. (2) Turmeric, 1 lb.; annatto, 2 oz.; shellac and gum juniper, each 12 oz.; wine spirit, 12 oz. (3) Seed-lac, 6 oz.; dragon's blood, 40 gr.; amber

and copal triturated in a mortar, 2 oz.; extract of red sanders, ½ dr.; oriental saffron, 36 gr.; coarsely powdered glass, 4 oz.; absolute alcohol, 40 oz. (very fine). (4) Seed-lac, 3 oz.; amber and gamboge, each 2 oz.; extract of red sanders, ½ dr.; dragon's blood, 1 dr.; saffron, ½ dr.; wine spirit, 2 pints. (5) Turmeric, 6 dr.; saffron, 15 gr.; hot alcohol, 1 pint. Draw the tincture and add—gamboge, 6 dr.; gum sandarach and gum elemi, each 2 oz.; dragon's blood and seed-lac, each 1 oz. (6) Alcohol, 1 pint; turmeric, 1 oz.; annatto and saffron, 2 dr. each. Agitate frequently for a week, filter into a clean bottle, and add seed-lac, 3 oz. Let stand, with occasional agitation, for about 2 weeks. (7) Gamboge, ½ oz.; aloes, 1½ oz.; shellac (fine), 8 oz.; wine spirit, 1 gal. (8) Put 3 oz. seed-lac, 2 dr. dragon's blood, and 1 oz. turmeric powder into 1 pint well-rectified spirits. Let the whole remain for 14 days; but during that time agitate the bottle once a day at least. When properly combined, strain the liquid through muslin, when it is ready for use. (9) To 5 oz. spirits of wine add gamboge enough to give a bright yellow colour, and 3 oz. seed-lac in fine powder. Put in sand-bath till dissolved. (10) Ground turmeric, as sold, 1 oz.; saffron and Spanish annatto, each 2 dr.; highly rectified spirits of wine, 1 pint. Place them in a moderate heat, shaking occasionally, for several days; then add 3 oz. good seed-lac, roughly powdered; shake occasionally till the lac is dissolved. If a deep orange lacquer is required, increase the quantity of annatto; if a bright yellow, decrease it. Lay it on with a brush (warm), like you would paint. One or more coats, if necessary. Avoid using too much seed-lac, as it has a tendency to prevent the lacquer lying evenly. (11) Pale gold lacquer is best for microscope; be sure and get the best (24s. per gal.), and see that the things are sufficiently hot before putting on the lacquer; heat after lacquering, and it will stand well. Damp will affect the best lacquering. (12) Is the best for optical work; if it comes off, either the metal was not clean when applied, or else it was put on cold. The metal should be heated to just such a point that it dries as fast as the brush passes over it. Work is often spoiled in lacquering. Circular things may be done in the lathe, going quite slow, and working a good body by going over several times.

(13) In preparing brass for the colourless or nearly colourless lacquer, the goods, after being annealed, pickled, scoured, and washed, are either dipped for an instant in pure commercial nitric acid, washed in clear water, and dried in sawdust, or immersed in a mixture of 1 part of nitric acid with 4 of water, till a white curd covers the surface, at which moment the goods are withdrawn, washed in clear water, and dried in sawdust. In the first case, the brass will be bright; in the latter, a dead flat, which is usually relieved by burnishing the prominent parts. Then the goods are dipped for an instant in commercial nitric acid, and well washed in water containing argol, to preserve the colour till lacquered, and dried in warm sawdust. So prepared, the goods are heated on a plate and varnished. The varnish used is one of spirit, consisting, in its simple form, of 1 oz. shellac dissolved in 1 pint alcohol. To this simple varnish are added such colouring substances as red sanders, dragon's blood, and annatto, for imparting richness of colour. To lower the tone of colour, turmeric, gamboge, saffron, Cape aloes, and sandarach are used. The first group reddens, the second yellows the varnish; while a mixture of the two gives a pleasing orange, and various tints can be got by suitable mixtures.

(14) Small circular work, after being well scoured, and burnished (if necessary), is best lacquered in the lathe. The work should be slightly warmed over a clear charcoal fire, or in a stove, and the lacquer applied very thinly with a soft camel-hair brush. A charcoal brazier should be held under the work for a few seconds, after the application of the lacquer, to prevent *chilling*. To lacquer a flat surface, clean carefully by

boiling in American potash and water. Dip in hydrochloric acid, if it be desirable to heighten the colour of the brass; wash well, first in cold water, then in hot (removing any black muddiness with a fine brush), and dry in hot sawdust. When dry, burnish if required. Place upon a flat iron plate, just lukewarm. Pass the lacquer quickly but evenly over the surface, by means of a rather large but fine camels'-hair brush. Be careful not to pass twice over the same spot, or a ridge is almost sure to appear. Warm the lower plate until the work is quite dry.

Bronze Lacquers.—(1) To make a bronze lacquer, dissolve ¾ lb. shellac and ½ lb. sandarach in 3 qt. alcohol, and add enough extract of dragon's blood and turmeric to produce the desired colour. (2) For ornaments bronzed with gold-coloured bronze, paint the articles, of cast iron, with white paint, which is white lead and oil; when hard dry, varnish with copal varnish; when sticky dry, dust the bronze powder over it; and when hard dry, brush off all the superfluous bronze with a camel's-hair brush. To protect it from the dust and from soiling, coat the bronze surface, when dry, with spirit copal varnish.

Brunswick Black.—(1) Many recipes for making this varnish do not mention the secret, viz., to boil the asphaltum until all the moisture is driven off. Take 7 lb. pitch and 7 lb. asphaltum, boil in an iron pot for 7 to 10 hours with frequent stirring. When all moisture is out, add 2 gal. boiled oil, previously heated, then add 2½ lb. red lead and 2½ lb. litharge, and boil for 3 hours, or until some of it will set hard. Then let it cool down, and add 5 gal. turpentine, or as much as will reduce it to the consistence best suited for your work. This varnish should dry in 20 minutes to 1 hour, according to the state of the atmosphere. You can try leaving out the red-lead but, add the extra in asphaltum, and also vary the quantity of oil. If wanted good and cheap, and 24 hours will suit, add more oil, less turps. (Mayer.)

(2) There are 2 kinds of Brunswick black—viz., best and common. The way the best is manufactured is as follows:—In an iron boiler, over a slow furnace, 90 lb. foreign asphaltum is boiled for about 13 hours, and at the same time 12 gal. boiled oil is re-boiled for 13 hours. During the boiling of the oil, about 12 lb. litharge is gradually introduced, and boiled until it becomes stringy. The boiler containing the oil is then emptied into the boiler containing the asphaltum. They are both boiled together until, upon trial, the mixture will roll into hard pills. The mass is then cooled, and mixed with 50 gal. turpentine. Common Brunswick black is made as follows:—112 lb. common black pitch and 112 lb. common asphaltum made from tar are put in an iron boiler, and boiled for 32 or 40 hours, by which time the gas and moisture will have evaporated. It remains standing for 2 nights, and on the third morning is re-boiled. As soon as it boils, 32 gal. boiled oil are added; then 40 lb. red-lead and 40 lb. litharge are gradually introduced, and boiled for 12 hours, or until it will roll very hard. When ready for mixing, 80 gal. turpentine are introduced, until the whole mass is of a proper consistency. This will dry in ½ hour, if properly boiled. (Crawford.)

Copper Lacquer.—Into a large-mouthed bottle, Ayres puts 500 gr. methylated alcohol, and 90 to 100 gr. pulverized gum lac. In another similar bottle he dissolves 90 to 100 gr. powdered bitumen in 500 gr. benzine. Shaking the bottles frequently, the solution is complete at the end of 2 or 3 days. The 2 solutions are mixed in equal proportions, and thickened to the consistency of cream with finely pulverized charcoal. It may be rendered more fluid, if required, by adding the proper quantity of a mixture of equal parts of alcohol and benzine. (*Soc. Franc. Photog.*)

Gold Lacquers.—(1) Pale lac, in grains, gamboge, dragon's blood, and annatto, each 12½ oz.; saffron, 3¼ oz. Each gum is dissolved separately in 5 pints alcohol, and the annatto and

saffron are separately infused in a like quantity of alcohol. The ingredients are mixed to form any particular tint desired. Turmeric (ground), 1 lb.; alcohol, 2 gal.; macerate for one week, strain by expression, and add gamboge, 1½ oz.; pale shellac, ¾ lb.; gum sandarach, 3½ lb. Strain, and add turpentine varnish, 1 qt. Other lacquers are prepared in a similar way from alcohol and shellac, a solution of the colouring ingredients, as dragon's blood, gamboge, &c., being kept on hand, and added to produce any required tint. (3) 2 parts seed-lac, 4 sandarach, 4 elemi, 40 alcohol. Alcoholic solutions of gamboge and dragon's blood, or fuchsin, picric acid, Martin's yellow, and coralline, are separately prepared, and added to the above in quantities ascertained by trial to impart the desired colour. To remove the marks left by the brush, and to impart lustre, the varnish, after drying, is polished. This is effected by first rubbing with powdered pumice and water, and next with an oiled rag and tripoli, until the desired polish is produced; the surface is afterwards dried with a soft linen cloth; any greasiness is removed by means of powdered starch, and the process is finished by rubbing with the hand. Great care must be taken that the surface to which varnish is applied be free from grease or smoke, which prevents all oil-varnish from drying. (4) Turmeric, 1 dr.; gamboge, 1 dr.; oil of turpentine, 2 pints; shellac, 5 oz.; gum sandarach, 5 oz.; dragon's blood, 7 dr.; thin mastic varnish, 8 oz. Digest with occasional agitation for 14 days in a warm place, then set aside to fine, and pour off the clear. (5) Dissolve gum lac in spirits of wine. (6) 1 lb. ground turmeric, 1½ oz. ground gamboge, 3 lb. ground gum sandarach, 1 lb. ground shellac (bleached), 2 gal. alcohol, 3 pints turpentine varnish. Put the whole into a suitable vessel, cork close, and agitate until dissolved. (7) 1 gal. methylated spirits of wine, 10 oz. seed-lac bruised, and ½ oz. red sanders; dissolve and strain. (8) A gold lac, remarkable for its great hardness and beautiful colour, on being analysed by Dr. R. Kayser at Nuremberg, gave as its constituents picric acid and boracic acid. Thereupon a clear shellac solution was mixed with picric acid and about ½ per cent. crystallized boracic acid, each being previously dissolved in alcohol, and the resulting lac possessed all the advantages of the former one.

Iron and Steel Lacquers.—(1) A black varnish, splendid in tone on steel or iron, is produced by turpentine and sulphur boiled together, laid on with a brush. The evaporation of the turpentine leaves a thin layer of sulphur, which unites with the iron when heated a short time over a gas or spirit flame. The varnish is durable and perfect. (2) 2 gal. spirits of wine, 1 lb. fine pale shellac; add to the above 3 oz. Cape aloes cut small, and 1 oz. gamboge cut small. Those who make lacquers frequently want some paler and some darker, and sometimes inclining more to the particular tint of certain of the component ingredients. Therefore if a 4-oz. phial of a strong solution of each ingredient be prepared, a lacquer of any tint can be produced at any time. (3) For cast-iron pipes use ordinary asphalte. Have a long cast tank set up on a small furnace underground. Asphalte is melted in it in sufficient quantity to entirely cover the pipe outside and inside, which is left in long enough to become the same temperature as the asphalte, then lifted out and well drained by holding the pipe vertically; a wooden cover keeps in the heat, and forms an extinguisher should the asphalte catch fire by overheating. (4) For hot-water pipes, lime or whiting whitewash mixed with size is a good varnish for protecting pipes; but nothing is better than blackleading, if appearance counts for anything.

Japanese and Chinese Lacquers.—Of late years, large quantities of Japanese lacquer-ware have been brought to this country in the course of trade, and sold often at remarkably cheap prices. The markets, indeed, have been quite glutted with Japanese manufactures; nevertheless, the works of real art in Japan lacquer always

realize a high price. It has been said that the process of lacquering, as known to the old Japanese workers, is, if not quite lost, becoming rapidly so in the present day, and that the modern system of lacquering is not calculated to stand the ravages of time, as was the work of a generation or two since. It is not to be supposed that the cheap lacquered articles of the present day, that are made simply to sell, will ever bear comparison in workmanship with the more costly and durable work, the make of which, as well as the polish, are, notwithstanding their great age, as perfect as when they left the hands of the workman.

The date of the discovery of the art of lacquering, in Japan, is given by the Japanese as A.D. 724; some authorities, however, consider it to have been later, probably indeed about 889 or 900. It seems, however, not to have attained to any degree of perfection till the year 1290, for the name of a distinguished painter in lacquer, who lived at that time, is still handed down as the founder of a particular school of art in lacquer-painting. From that time, it developed until it attained its present perfection.

A very elaborate report on the lacquer industry of Japan has recently been produced by J. J. Quin, H.M. Acting Consul at Hakodadi. This report has been drawn up chiefly as a description of the articles of various kinds illustrative of the lacquer industry of Japan, collected for the use of the Museum of Economic Botany at Kew. This collection is a most complete one, and is now exhibited in the No. 1 Museum, Royal Gardens, Kew. It comprises not only a fine series of finished lacquer articles, such as boxes, cabinets, bowls, trays, &c., both of ancient and modern workmanship, but also a very complete set of the instruments and appliances used in the manipulation of the lacquer-ware, including specimens of the trunk of *Rhus vernicifera*, gashed to show the mode of extracting the juice or lacquer, together with the iron instruments used for this purpose; also a complete set of the lacquers themselves, and of the colouring matters used.

The following notes are abstracted from the report referred to, which is probably the most detailed account ever written of the lacquer manufactures of Japan. In his introduction the writer says great difficulty has been experienced in obtaining thoroughly reliable information, as not only are the artificers for the most part uneducated, but they are entirely ignorant of what takes place in any other department, except that to which they have been brought up. A well-known and most intelligent manufacturer, Takei Tôsuke, who has been over 20 years himself a worker in gold lacquer, and from whom great assistance has been derived in bringing together the present collection, was quite unaware of the mode of tapping and treating the trees, and had never seen a cut specimen of the wood until the pieces now forwarded were procured. He states that his head workman, a highly-skilled artisan, over 50 years of age, hardly knows the name of a single article that he uses.

The *Rhus vernicifera*, the well-known lacquer-tree of Japan, is met with all over the main island, and also in smaller quantities in Kiushiu and Shikoku, but it is from Tôkiô northwards that it principally flourishes, growing freely on mountains as well as in the plains; thus indicating that a moderate climate suits the tree better than a warm one. Since early days, the cultivation of the tree has been encouraged by the Government in every province and district. The lacquer-tree can be propagated by seed sown at the end of January or the beginning of February. The first year the seedlings reach a height of 10 in. to 1 ft. The following spring the young trees are transplanted about 6 ft. apart, and in 10 years an average tree should be 10 ft. high, the diameter of its trunk 2½ to 3 in., and its yield of lacquer sufficient to fill a 3-oz. bottle.

A more speedy method is, however, generally adopted. The roots of a vigorous young tree are taken, and pieces 6 in. long and the thickness of a finger are planted out in a slanting direction a few inches apart, 1 in. being left ex-

posed above the ground. This takes place in the end of February and through March, according to the climate of the locality. These cuttings throw a strong shoot of 18 to 20 in. the first year, and are likewise planted out the following spring. Under equally favourable circumstances, these trees would be in 10 years 25 per cent. larger in girth, some 2 or 3 ft. higher, and would yield nearly half as much more sap than the trees raised from seed.

It has not hitherto been the custom to bestow any special care on the trees after planting them out, but in cases where leaf or other manure has been applied they are much finer. Of late years, hillsides and waste grounds have been used for lacquer plantations, as owing to the rise in price of cereals and farm produce generally, it does not pay the farmers to have their land cumbered with trees. Those that have been hitherto planted along the borders of fields are being rapidly used and uprooted, and, where practicable, mulberry-trees are planted instead, with a view to rearing silkworms. Nevertheless, as a good workman is expected during the season to tap 1000 trees 10 years old, and as the province of Yechizen alone sends out 1500 "tappers" yearly to the various lacquer districts, it will be seen that an immense production annually takes place, stimulated doubtless by the demand for cheap lacquered articles abroad. It should also be mentioned that to remedy the possible exhaustion of the supply, and in view of the great rise which has taken place in the price of lacquer, several companies are being projected to plant waste lands with the tree. A 10-year-old tree, which some 5 years ago only cost 1 to 2 sen, now costs 10 sen, which, allowing even for the depreciation in the value of paper currency, shows a rise of about 500 per cent.

The best transparent lacquer comes from the districts of Tsugaru, Nambu, Akita, and Aidzu. It is largely used by the workers of Kioto, Osaka, and the southern provinces, but though also used in Tôkiô, is not so much appreciated there as the lacquer produced from the neighbourhood of Chichibu, in the province of Mus-ashi, from Nikko, in Shimotsuke, and that produced in the provinces of Kodzuke and Sagami, which hardens more rapidly, and is the best for black lacquer. There are some districts the lacquer obtained from which is best for certain kinds of work, but is not so well adapted for others. The kind which is used for transparent lacquer is mixed in large tubs, to ensure a uniform quality, and being allowed to stand for some time (say a week or 10 days), the best portion, which is ordinarily 70 per cent. of the whole, is skimmed off. This is used for Nashiji and Shu lacquer, while the remainder is used for making inferior mixtures, such as Johana, &c. Almost all the various classes of lacquer are similarly dealt with to ensure uniformity, as some qualities dry much quicker, and are better than others, and the slow-drying qualities would otherwise remain unsold.

The whole country produces on an average 30,000 to 35,000 tubs per annum, each tub being of about 4 gal. capacity. Some 70 to 80 per cent. of this total amount is produced from Tôkiô northwards. Nearly ½ the lacquer produced is sent to the Osaka market, where it is prepared as required, and resold all over the western and southern provinces, the remaining portion being used up locally and in Tôkiô.

The usual age at which a tree is tapped is 10 years, but in some few cases a tree is tapped when only 3 or 4 years old. The best lacquer for transparent varnish is obtained from trees 100 to 200 years old, as their sap has more body and is more glutinous. The tools used in obtaining the lacquer are as follows:—

Kawa-muki (bark-parer), a curved knife, with which the workman smoothes all inequalities of the bark before tapping the tree.

Eda-gama (branch sickle), an instrument with a gouge on one side and a knife on the other, fitted with a piece of bamboo to give the hand a good hold when tapping branches.

Kaki-gama (scraping sickle), a similar instrument, without the piece of bamboo, used for tapping trees generally.

Yegwri (a gouge), used in autumn to scrape the bark smooth before giving the final cut with the Kaki-gama.

Natsu-bera (summer spatula), used for scraping the sap out of the incision into the receptacle named *gō*.

Hōchô (knife), used for cutting the bark of branches in obtaining *seshime* or branch lacquer.

Seshime-bera (*seshime* spatula), used for collecting the sap which exudes from the incisions in the bark of the branches.

Gō, the bamboo or wooden pot in which the sap is put as it is collected.

Gō-guri (pot-gouge), a long straight knife for scraping the lacquer out of the pot into the tub.

Te-bukuro (glove), worn by the tapper to protect his hand from contact with the sap.

The first tapping takes place about the beginning of June. The standard number of trees allotted to a tapper for the season is 1000, presuming them to be about 10 years old, or about 800 of the older trees, and so on, less and less according to the size of the trees. Having cleared away the grass from the roots, the workman makes the round of his allotted trees, marking each with small notches about $\frac{1}{2}$ in. long. The first of these notches is made about 6 in. from the bottom of the tree on the right-hand side; the next, one "hand stretch" higher up on the left-hand side; the next, one "hand stretch" higher on the right; and so on, alternately, as far as the workman can reach. These preliminary markings, which are to determine all the places for subsequent tapping, take fully 4 days, being at the rate of 250 trees a day. The tapper then goes round provided with the bark scraper, the ordinary scraping sickle, the summer spatula, and the pot to hold the lacquer; and first smoothing the bark where required, gives one cut above and one cut below the two lower marks, and one cut above the remainder of the other marks, the cut being in each case about $1\frac{1}{2}$ in. long. After giving the cut, the instrument is reversed, and the knife is run along the incision to ensure the bark being entirely cut through. This process is repeated every 4 days, each incision being made a little longer than the preceding one, up to the fifth tapping inclusive, after which the remaining incisions are made of the same length. At each round, when all the requisite incisions have been made on the tree, the workman gathers the sap, which has been exuded, with the spatula, beginning with the 2 lowest incisions, and so on to the uppermost cut; 25 is considered the normal number of cuts, which, at the rate of one incision at each place every 4 days, occupy 100 working days, and allowing for some 20 days of rain, during which the sap cannot be drawn, the season is brought to a close about the end of September. If the workman has any large trees to tap, the whole of which he cannot reach, when his round is concluded, he returns with a ladder, and, mounting each tree, taps the remainder of the trunk and the leading limbs in the same manner as above described, previous to making a fresh round.

When the full number of incisions has been given, the workman gives an extra long cut underneath all the initial notches on each tree to obtain the sap which has collected there, and another above the uppermost cut of each set. These incisions are called *ura-me* (back marks). The workman also makes a number of cuts, each about 1 ft. apart, in all the branches whose diameter exceeds 1 in. This operation requires about 16 days to get through the whole number of trees. The next operation is called *tomé* (the finish). This consists of a number of incisions completely encircling the tree wherever the workman perceives a likely place. The next process consists in cutting off all the branches; the larger ones are once more tapped after being cut off, to extract any sap that may still remain in them, and the small branches, which have not yet been tapped, are tied in bundles and

steeped in water for about 10 days. When taken out and dried, the bark is cut with a knife, and the sap which exudes is collected with a branch spatula, and is called *seshime* lacquer. This word seems to be derived from *sehi*, the name of a machine, and *shimeru* (to press), from a practice which obtained in olden days of pressing the branches in such a machine to obtain the sap. It is also known as *yeda urushi*, or branch lacquer.

The sap obtained from the first 5 cuts above each notch is poor, containing, as it does, a large proportion of water; the middle 15 cuts produce the best sap, and the sap obtained from the last 5 incisions is poor, and lacks consistency. Again, the sap obtained from the *ura-me* (back marks) and *tomé* (finishing) cuts, is very good, and dries quickly. The sap from the first 25 cuts is mixed and sold together; but the *ura-me* and *tomé* sap is almost always mixed and sold separately. The operations above described kill the tree in one season, but frequently the tree is made to last 2 years or more by giving only half the number of incisions, and reserving the *ura-me* and *tomé* cuts for the final year. The sap obtained the second and following years is, however, of an inferior quality, and this method is only resorted to by private individuals, who tap their own trees during intervals of farming. Ordinarily a wholesale dealer in lacquer buys so many thousand trees from the owner, and, as a matter of course, extracts the sap with as little delay as possible, making a contract for the purpose with professional tappers. A first-rate workman will receive over 100 yen (equal, at the present low rate of exchange, to nearly 13*l.* sterling) for the season, and can collect 4½ tubs (equivalent to 18 gal.); but the average receive 75 yen, and collect proportionally less. The present price per tub of lacquer ranges from 90 to 100 yen. After the sap has been taken, the exhausted tree, which remains the property of the seller, is cut down by him, and is used for firewood, for building purposes, or for making boxes.

The roots of the young trees throw 3 to 5 shoots the following spring, and these can be used in 6 or 7 years. Of these 5 sprouts 3 are commonly much stronger than the other 2. In such cases, the strong ones only are tapped and cut down, the weaker ones being allowed a year or two longer to grow, when, receiving the whole of the nutriment, they shoot up in 1 year as much as an ordinary tree would in 3. After tapping and cutting down, fresh shoots to the number of 5 are again allowed to sprout, and so on, the root not seeming to become exhausted by the process; but when a very old tree is cut down, the roots will not give out new shoots. In the northern provinces, very old and large trees are met with in considerable quantities. These were kept for the sake of their berries, from which the wax used for the Japanese candles was obtained.

This was the more profitable use to which to put the tree, as a good tree, from 80 to 100 years old, yielded yearly, on an average, equal to 6*s.*; while the price of a 10-year-old tree, to be used for extracting the sap, was under 1*s.* 2*d.* Previous to the revolution of 1868, every tree reserved for making wax was officially registered, and the owner was not allowed to mutilate it in any way. Even if a tree died, he had to get official permission before removing the stump. The Shogun's Government, and also the local magnates, had large plantations of the lacquer-tree reserved for wax, but since the opening of the country to foreign trade, and the introduction from abroad of kerosene oil, the wax industry has greatly declined, and there are now no restrictions on the free sale of the tree for tapping, and, consequently, all the fine old trees (which will sell at 5 to 6 yen each) are fast disappearing.

To show the relative value of the berries and the trees a few years ago, the following may be cited:—A wholesale lacquer merchant 5 or 6 years ago went, as usual, to purchase trees in the district of Aidzu, and among others bought one tree for a yen (then equal to 4*s.*), the owner reserving the berries

that might be got as his own property. He does not consider the bargain was a cheap one, but the owner realized a sum of 80 sen (equal to 3*s.* 2*d.*) from that year's yield of the berries alone, before cutting down the tree.

It should be mentioned that the above description of the method pursued in tapping the lacquer-tree is that which is recognised as the proper one, but the rule is not rigidly observed, the style and size of the tree, and the caprice of the workman, combining to cause variations in the number of incisions given in each series.

The woods chosen for lacquering on are naturally selected according to the use to which the lacquered article is to be put. For shelves, cabinets, boxes of all kinds, the following are principally used, and are set down in the order of their excellence:—*Hinoki* (*Chamæcyparis obtusa*): by far the best wood for making boxes, as it does not warp. *Kiri* (*Paulownia imperialis*): light wood used for clothes-boxes, which are only lacquered on the outside. It is also used for making tea-caddies, as the wood has no smell. *Hōno-ki* (*Magnolia hypoleuca*): sword sheaths have hitherto been made of this wood. *Sugara* (*Chamæcyparis pisifera*): a wood of a coarser grain than *Hinoki* (*C. obtusa*). *Hime-ko-matsu*: used for carved figures of men, animals, &c. It is not liable to split and crack. *Tsuga* (*Abies tsuga*), *Hiba* (*Thujopsis dolabrata*): for making cheap articles. *Akamatsu* (*Pinus densiflora*), *Sugi* (*Cryptomeria japonica*): only used in making the cheapest and most inferior goods. The following woods are mostly used in the manufacture of such articles as are turned in a lathe, as bowls, rice-cups, round trays, &c.:—*Keyaki* (*Planera japonica*), the best being obtained from the province of Hiuga. *Sugi*, the scientific name of which is unknown. *Sakura* (*Prunus pseudocerasus*). *Katsura* (*Cercidophyllum japonicum*). *Toho* (*Ginkgo biloba*). *I-yo*: grown in large quantities in the neighbourhood of Hakone. It is principally used in the manufacture of cheap articles. *Buna*: principally used in the district of Aidzu for the same kind of utensils as *keyaki* and *sakura*, but being a brittle wood, it cannot be turned in a lathe to make such fine articles; those made of this wood are coarse and heavier. For raised gold lacquering over unvarnished surface, the following hard ornamental woods are often used:—*Shitan*, *Tagayasan*, *Karin* (quince), *Kuwa* (mulberry), *Keyaki* (*Planera japonica*), ornamental grain.

VARIOUS KINDS OF LACQUER AND MIXTURES USED.—(A) FOR PLAIN WORK.—*Ki-urushi* (crude lacquer) is the generic name by which all lacquer obtained from the trunks of live trees is known. It forms the basis of nearly all the various mixtures used in making lacquer ware.

S. shime (branch lacquer).—This kind is obtained from the branches of the trees as described above; but the yield is only 1 per cent. in comparison with other lacquer. As, however, in working, the proportion of nearly 90 per cent. is required, the lacquer manufacturers sell a mixture which is stated to be a compound of true branch lacquer, the best crude lacquer, *ura-ne* and *tomé* lacquer, *funori* (seaweed jelly), sweet potatoes grated fine; the whole coloured as may be necessary with soot. The proportions in which these materials are used cannot be ascertained, and indeed each manufacturer uses his own special mixture, but the extraneous additions are believed not to injure the quality of the whole. True branch lacquer becomes extremely hard when once dry, but used alone will not dry under some 20 days: so that now, when time is an object, the pure sap is but little used.

Previous to the revolution of 1868, branch lacquer of a very superior quality, and which would dry quickly, was obtained by using the young shoots which sprouted yearly from the roots after the trees had been cut down. This kind was called *Ki-seshime* (crude branch), and was made under directions of the Government, who received it as taxes: but the practice has been discontinued of late. The price of pure branch lacquer is, owing to the difficulty in drying, only 70 per cent. of ordinary good lacquer.

Rō-urushi (black lacquer).—This is made by adding to crude or branch lacquer, about 5 per cent. of the tooth dye (*haguro*) used by women, a liquor formed by boiling iron filings in rice vinegar, and exposing it to the sun for several days, stirring the mixture frequently till it becomes a deep black.

In preparing all lacquer—from the crude lacquer to the various mixtures—the principal object is to get rid of the water that exudes from the tree with the sap. To effect this, it is exposed in broad flat wooden dishes, and stirred in the sun. This, however, alone will not cause the original water to evaporate, so from time to time—ordinarily about 3 times in the day—a small portion of clean water is stirred in, say 1 per cent. each time, for 2 or 3 days, according to the heat of the sun. All the water then evaporates together. No lacquer will dry until this process has been gone through. If the lacquer is old—*i.e.*, has been tapped a long time before using—it is much more difficult to dry. In such a case, a portion of fresh lacquer is added to the old by wholesale dealers, or else the manufacturers, instead of water, sometimes mix *salé* (rice beer) or alcohol to "quicken" it.

A very remarkable property of lacquer should be mentioned. If crude lacquer, which is originally of the colour and consistency of cream, is exposed to the son for a few days without adding water, it loses its creamy colour, and becomes quite black, or nearly so, but also becomes thinner and transparent, or rather translucent, as can be seen when it is smeared on a white board. It will not now, however, dry if applied to an article, even if kept a month or more in the damp press. But if water is mixed with the lacquer which has thus been exposed and become black, it at once loses its black colour and transparency, and becomes again of a creamy colour, though slightly darker, as if some coffee had been added, than at first. After evaporating this water, it can then be used like any ordinary lacquer, either alone or in mixtures, and will dry in the damp press, during which process it again turns black. What lacquer-workers have found their greatest stumbling-block is the difficulty of obtaining a clear, transparent varnish. What is called transparent varnish is really black to the eye, and requires grinding and polishing after application before it presents a brilliant surface, becoming also much lighter after a little time.

It would be a new era in the manufacture of lacquer-ware if a method could be discovered of rendering the lacquer varnish perfectly clear and light-coloured, when so desired, without depriving it of its drying qualities, and also if colours could be used with it other than those hereafter mentioned.

Nakanuri-urushi (middle-painting varnish).—This is merely the crude lacquer. After having been exposed for some time to the sun to darken it, and to get rid of all water, it is used for under-coats for making first-class ware.

Nuritate-urushi (finishing lacquer).—This is a mixture of crude lacquer and a little turpentine with *tō-midzu* (whetstone water), being the mixture obtained from whetstones on which blades have been sharpened. In it is some 7 to 8 per cent. of iron, and after mixing, the whole is exposed to the sun, both for the purpose of getting rid of all the water, and to darken the colour. This is used for final coats of cheap lacquer, which is not polished afterwards.

Jō-hana-urushi.—This is a mixture of the above kind, with oil obtained from the *ye* plant (*Perilla ocymoides*). This is used for still more common kinds requiring no after polishing, and the lacquer does not present a hard surface.

Jō-chiu, called in Kioto, *Chiu-hana*; *Jō-tame*, called in Kioto, *Ge-hana*.—These contain more and more oil, and are used for the commonest articles, such as for varnishing clogs, clothes-baskets, &c. These 3 last kinds give a high polish, but the lacquer does not last.

Shu-urushi (vermilion lacquer).—This is the best crude or transparent varnish mixed with *ye* oil (*Perilla*

ocymoides), sometimes as much as 50 per cent. being added. It is then exposed to the sun, and water is added, which is afterwards evaporated. This kind is only used for red (whence its name) and coloured lacquers; the colours being added at the time of application. It requires no after-polishing.

(B) FOR LACQUERING WITH GOLD.—*Nashiji-urushi* (pear basis lacquer), or *Suki-urushi* (transparent lacquer).—The first name is that best known in the trade, as indicating that it is required for using over gold, silver, or tin powdering. It consists of the finest crude lacquer obtained from old trees. As stated previously, the lacquer is allowed to stand till all dirt and foreign matter have sunk to the bottom, when the best is skimmed off, and after being exposed to the sun to evaporate the water in the usual manner, and carefully filtered, it is ready for use. Except when used for the highest class of gold powdering, a certain proportion of gamboge is mixed with the lacquer to give the dust a fine yellow colour.

N.B.—The following 10 kinds are all bought by the lacquer-workers ready prepared from the manufacturers. Any further mixtures used by them are made as required, colours added, &c.

Seshime-urushi (branch lacquer) and *Rō-urushi* are used also in making gold lacquer.

Yoshino-urushi.—This is crude lacquer from the district of Yoshine, in the province of Yamato. It dries quickly, and closely resembles transparent varnish. It is used when giving the final coats before polishing.

Yoshino-nobe-urushi (Yoshino spreading lacquer).—Same as above, with the addition of about ¼ of camphor to render the lacquer thinner and more easy to spread.

Seshime-nobe-urushi (spreading branch lacquer).—This is merely branch lacquer with the same proportion of camphor as above; when cheap work is required, more camphor is used till the proportions are reversed. This renders the mixture very soft, and a small quantity can be spread over a large surface.

Shita-maki-urushi (under-coat lacquer).—A mixture of branch lacquer and *benigara* (red oxide of iron), in equal parts by weight.

Ke-uchi-urushi (inside line lacquer).—This is the same as above, but it is allowed to stand for about 6 months after mixing before it is used. By this time it has got thicker, and the very finest lines can be drawn without fear of their running; they, moreover, stand out better.

Shita-maki-nobe-urushi (under-coat spreading lacquer).—Same composition as above, with the addition of a little camphor to make the lacquer thin. It thus goes much further, and causes a great saving when lacquering with powdered gold-leaf (*keshi fun*), for which it is best suited. As in the other mixtures, the more camphor is used, the thinner it renders the lacquer, and the less gold is required.

Taka-maki-urushi (raised lacquer).—To make this, a certain quantity of *ro* or *nuritate* is taken and divided into 3 parts. To 1 part is added lampblack and camphor, in equal proportions of bulk. These, after being well mixed, are boiled together; then the other 2 portions are added, and the whole stirred together, and afterwards filtered through paper. It is boiled more or less according to the season. In summer, when lacquer dries quickly, it is boiled for a longer period; while in winter or during cold weather, when lacquer naturally takes longer to dry, the mixture is boiled for a shorter time. The reason why *Taka-maki* is thus purposely rendered soft, is explained by the fact that otherwise the upper surface would harden at once, while the under portion, *Taki-maka* (being applied thickly), being excluded from the upper air, would not be able to dry, and later, the top surface would crack and show fissures; whereas the introduction of camphor renders it soft and much slower to dry, and the whole has thus time to harden equally. Camphor being volatile, is gradually lost, and the composition becomes quite hard.

Ro-se-urushi (a mixture of black and

branch lacquer).—This is used for the lacquer coating upon which gold, silver, or tin powder is scattered, except in such cases where the grain of the wood is to be shown, when *Nashiji* lacquer is used instead.

Kuma-urushi (shading lacquer).—A mixture of *Jōkana* lacquer and lampblack, used for final shading in the feathers of birds or animals, or for drawing hair, &c., on flat and raised gold lacquer.

It should be noticed that whenever lampblack is mentioned as a mixture, it is used for the superior kinds, wood- or coal-soot being used for inferior articles.

IMPLEMENTS AND MATERIALS USED IN THE MANUFACTURE OF PLAIN LACQUERED WARE. — *Hera.* — A spatula made of *Hinoki* (*Chamæcyparis obtusa*), used for applying the under or priming coats and for mixing the lacquer.

Haké. — A flat brush made from human hair, used for laying on the lacquer.

Kokuso. — Finely-chopped hemp. Mixed with lacquer, it is used for covering joints.

Nuno.—Hempen cloth, used for pasting over the wood to prevent it splitting, and to strengthen corners, &c. For very fine work and small articles, silk is used.

Ji-no-ko (burnt clay).—Afterwards reduced to a very fine powder. Pounded bricks are often used.

To-no-ko.—A fine kind of clay, which is procured from Mount Mari, near Kioto. This is likewise burnt, and reduced to a fine powder.

Sumi. — Charcoal made of *Hōnoki* (*Magnolia hypoleuca*), used for smoothing down the under-coats; it has rather a rough grain. Also charcoal made from *Hiyakujikkō* (*Lagerstræmia indica*). This is very soft and of a fine grain, and is used for the final smoothing before hand-polishing. This kind is called by the trade *Kō-iro-sumi* (black-coloured charcoal).

To-ishi.—Whetstones of 4 different qualities of fineness: *Ara-to* (rough), *shiro-to* (white), *awo-to* (green), and *najura*, the last being the finest. These are used for smoothing down the priming coats.

Tsuno-ko (horn powder).—This is made of calcined deer's horns reduced to a fine powder, and is used for the final polishing with the finger.

To-kusa (*Equisetum*). — A kind of scouring rush, used for smoothing the lacquer.

Kaki-no-shibu (persimmon juice).—This is used when no ground lacquer is required, as in the Aidzu lacquer, or when the grain of the wood is shown.

Nikawa (glue).—This is used to mix with the groundwork for cheap kinds of ware, instead of lacquer.

Yuyen-sumi (lampblack).—Used for groundwork of cheap articles, mixed with persimmon juice. For still more common ware, soot of any kind is used.

Gofun (whiting)—Made from burning old shells, such as are obtained from the ancient kitchen middens; used for mixing with glue to make the groundwork of common lacquer.

Shō-no (camphor).—Used for mixing with lacquer, to make it thinner and spread more easily.

Hōchō (knife).—Used for scraping off all inequalities of the hempen cloth after it is pasted on the article, &c.

Yoshino-gami.—A very thin kind of paper, made at Yoshino; used for filtering the lacquer before using it.

Jō-ban.—A box with a very hard lacquered lid, usually containing drawers for the various pencils, &c. The lid is used for mixing the lacquer on while working.

Tsuno-ko-ban.—Board for mixing and powdering the deer's-horn ashes before using: generally made of cherry-wood or oak.

Muro.—A cave or cellar underground is used, where practicable; otherwise, an air-tight case, made of wood, with rough unplaned planks inside. These are thoroughly wetted before the lacquered article is put in to dry, which occupies a period varying from 6 to 50 hours, according to the time of the year or style of the lacquer. Lacquer will not dry or harden properly in the open air; it absolutely requires a damp closed

atmosphere to do so, otherwise it would run and always remain sticky.

The following are mixtures made by the workmen as required:—

Kokuso.—A mixture of finely chopped hemp, with rice starch and branch lacquer sufficient to make a thick paste.

Jino-ko (No. 1).—Powdered burnt clay and branch lacquer, mixed together in the proportion of 1 part of clay to 2 parts of lacquer.

Jino-ko (No. 2).—The same, mixed in the proportion of 10 parts of clay to 13 of lacquer, and a little water.

Jino-ko (No. 3).—The same, mixed in the proportion of 10 parts of clay to 8 parts of lacquer and 2 parts of thin rice starch. This mixture is known in the trade as *Han-dan-ji* (half-step basis).

Jino-ko (No. 4).—The burnt-clay powder mixed with liquid glue only in such proportions as will resemble the consistency of lacquer.

Kiri-ko.—A mixture of *Jino-ko* and *Tōno-ko* in equal portions with 1½ of branch lacquer. This becomes very hard.

Sabi.—A mixture of 2 parts of the burnt clay from Mount Mari to 1½ of branch lacquer, with just sufficient water to mix the clay into a paste.

An inferior class of *Sabi* is made by putting in less lacquer—as little as 8 parts of lacquer being used to 20 of the clay. Less lacquer cannot be used, as it would not stand polishing after having been dried.

Mugi-urushi.—Wheat lacquer; being a portion of wheaten flour mixed with branch lacquer to such consistency as may be required. It is used to paste the hempen cloth on to the wood.

Shin.—A mixture of rice flour with branch lacquer, used for the same purpose as wheat lacquer. Wheaten flour is the best, but being more difficult to blend with lacquer it is not so much used.

Ka-no-ji.—A mixture of whiting and liquid glue, used for under-coats or cheap articles.

Shibu-ji.—A mixture of lampblack and persimmon juice, used for under-coats in inferior ware.

The following are the modes of applying the lacquer:

(*a*) *Honji* (real basis).—The article to be lacquered is first carefully smoothed, and the wood is slightly hollowed away along each joint, so as to form a circular depression. The surface of the whole article is then given a coating of branch lacquer (this is called *Ki-ji-gatame*—hardening the wooden basis), and the article is set to dry in the damp press, or *muro*, for about 12 hours. The hollowed portions are filled with prepared *Kokuso*, which is well rubbed in with a spatula made of the wood of the *Chamæcyparis obtusa*, and the article is enclosed in the drying-press for a period of at least 40 hours. Over the *Kokuso* a coating of *Sabi* is applied, and set to dry for 12 hours. The next process is to smooth off with a white whetstone any roughness or inequalities of the *Kokuso* and *Sabi*. The article is then given a coating of wheaten lacquer, over which is stretched hempen cloth, great care being taken to spread it smoothly and leave no wrinkles or perceptible joinings, and it is then again enclosed in the drying-press for about 24 hours. After taking the article out of the press, all inequalities in the cloth—which has now under the influence of the lacquer become harder than wood—are smoothed down with a knife or with a plane. Next, a coating of *Sabi* is applied with the spatula, to hide the texture of the hempen cloth, and the article is again put in the press for 24 hours. Next, a coating is given of No. 1 *Jino-ko*, applied with the spatula, after which the article is enclosed in the drying-press for 24 hours, and this process repeated. Next, the article is given a coating of *Kiriko*, likewise applied with the spatula, and the drying process is repeated for 24 hours; there is then a repetition of the same process, after which the article is set to dry for at least 3 days. The surface is next ground smooth with a fine white whetstone, and a hardening coat of branch lacquer is given with a spatula, and set to dry for 24 hours. A fresh coat of *Sabi* is applied with the spatula, and the article is put to dry in the press

for 24 hours. When thoroughly hardened, the surface is ground with a white whetstone, as before. Next, a thin coating of branch lacquer is applied with the spatula, and the article is set to dry in the press for 12 hours. A coating of *Naka-nuri* is applied with a flat brush (*Hake*), and the article is set to dry again for 24 hours. On being taken out, the surface is ground smooth with charcoal made from *Hōnoki* (*Magnolia hypoleuca*). A thin coating of branch lacquer is given with cotton wool—old wool being chosen because less likely to leave hairs behind it—and rubbed off again with soft paper, after which the article is set to dry for 12 hours. A coating of *Rō* (black lacquer) is then applied, and the article is set to dry for 24 hours. The surface is rubbed smooth with a piece of charcoal made from *Hiyakujikko* (*Lagerstræmia indica*). The surface is partly polished with finely powdered *Lagerstræmia* charcoal, applied with a cotton cloth. A coating of *Rō* is applied very thinly with cotton wool, and this is rubbed off again with soft paper, after which the article is enclosed in the drying-press for 24 hours. The surface is now polished with an equal mixture of powdered burnt clay from Mount Mari (*To-no-ko*) and calcined deer's-horn ashes, applied with a cotton cloth and a little oil (made from *Sesamum orientale*) till a fine polish is obtained. A coating of branch lacquer is next given, applied with cotton wool very thinly, and the article is enclosed in the drying-press for 12 hours. The workman dips his finger in oil and rubs a small quantity of it over the surface, which he then polishes with deer's-horn ashes, applied with a cotton cloth, till a bright surface is obtained. A coating of branch lacquer is applied thinly with cotton wool, wiped off with soft paper, and set to dry for 12 hours. Oil is again applied, and then a final polishing with deer's-horn ashes given with the finger to the surface, which now assumes the most brilliant polish of which it is capable.

For articles that are liable to get rubbed, such as scabbards, these last 2 processes are repeated 7 or 8 times, the surface getting harder at each repetition; but this is not necessary for other articles, even of the best quality. In describing the above processes, the *minimum* time for drying has in each case been given, but for the first 25 processes the longer the article is kept in the press the better. From the twenty-eighth process to the finish it is better not to greatly exceed the times mentioned.

(*b*) *Kata-ji* (hard basis); (*c*) *Handan-ji* (half-step basis); and (*d*) *Manzo* (after a lacquer-worker of that name) —modifications of the first process.

(*e*) *Ka-no-ji* (inferior basis).—In this class the joints of the article to be lacquered are frequently not hollowed away, a strip of paper being merely pasted over them, and even this precaution being often omitted. A coating of *Ka-no-ji* (whiting and glue) is applied with a spatula twice or thrice, and dried in the sun. The article is then wiped over with a wet brush and rubbed smooth with a white whetstone, and afterwards given an extra smoothing with the spatula. Sometimes a thin coating of *Nukanuri* or of branch lacquer is given to the article, but more frequently a coating of glue and lampblack, or of glue and soot mixed together, is applied. A final coating of either *Jō-hana* or *Jō-chiu* finishes the process without any subsequent polishing.

(*f*) *Shibu-ji* (persimmon-juice basis). The joints of the article are prepared in the same manner as for (*e*), but instead of *Ka-no-ji*, 4 or 5 coats of *Shibu-ji* (persimmon juice and lampblack) are applied with a brush; these dry very rapidly, and the last coating is smoothed with *To-kusa* (*Equisetum*). A final coating of either *Jō-hana* or *Jō-chui* is given. This kind of article is chiefly made in Aidzu, and indeed goes by the name of "Aidzu ware." It has not such a good appearance as *Ka-no-ji*, for the grain of the wood is easily traceable under the lacquer, but being made without glue, it stands water much better, and is in general request for rice-bowls and *zen* (small dinner-trays

with legs, one of which is set before each guest).

(*g*) *Sabi-Sabi* (double Sabi).—In this class of goods the joints are generally hollowed out, and a basis-hardening coat of branch lacquer is given. Paper is also pasted over the work after filling in the joints with *Koku-so*. Three coats of inferior *Sabi* are then applied, and after drying for about 12 hours in the press, the article is ground smooth with a white whetstone. Next comes a coating of branch lacquer, applied with cotton wool, and then one of *Naka-nuri*, which is ground smooth with *Magnolia* charcoal. Another coating of branch lacquer is followed by one of *Jō-hana* or *Jō-chiu*, and the article is finished without further polishing. Drying in the damp press is requisite after each process for this class of lacquer. It is manufactured only in Tōkiō, though the processes for the under coats of *Wakasa* lacquer are identical. Rice-bowls, drinking-cups, and luncheon-boxes, &c., are the usual articles manufactured. In this, as in Aidzu ware, the grain of the wood is traceable, and its common appearance constitutes the reason for classing it so low, but in actual excellence and durability it ought to rank fourth next to *Hundan-ji*.

(*h*) *Kaki-awase* (mixture), or *Kuro-shunkei* (black Shunkei), from the name of its inventor. In this class of goods the wood is given a basis-hardening coat of branch lacquer mixed with lampblack, over which is laid a final single application of *Jō-hana* or *Jō-chiu*. This ware is made at Tōkiō, and is used for cheap rice-bowls and boxes. For the commonest kind of work a mixture of glue and lampblack, or persimmon juice and lampblack, is used, instead of branch lacquer, as a ground coat.

(*i*) *Aka-shunkei* (red Shunkei).—This kind also derives its name from the inventor. For making articles of this class, which show the natural grain of the wood, a mixture of *Yoshino* lacquer and gamboge is rubbed on with a hard brush, after which they are enclosed for a day in the press to dry, and then a coating of *Shu-urushi* (transparent lacquer, containing a proportion of *Perilla ocymoides* oil) is applied. When dry, it presents a polished surface, and it appears dark when at first finished, but in a few months becomes much lighter. A cheaper quality of *Shunkei* is made by using glue and gamboge or persimmon juice and oxide of iron for the undercoat, but though the colour has a better appearance at first, it gradually deteriorates. The best is made in the province of Dewa, at Akita. For the most part soft woods are used in making this ware.

(*j*) *Ki-ji-ro* (colour of the grain of wood).—Well-seasoned wood is selected, and the article having been carefully smoothed, a thin coating of *Yoshino* lacquer is applied with a brush, after which it is set to dry in the press for 12 hours. A coating of best *Sabi* is then applied with the spatula, and set to dry in the press as usual. This is ground completely away with a green whetstone. A coating of *Nashiji* (pure transparent lacquer) is now given, and the article is enclosed in the press for 24 hours. It is again ground with a green whetstone till no remains of the lacquer coating are apparent. Then follows a second coat of transparent lacquer, which, after drying as before, is ground smooth with a piece of *Hiyaku-jikko* (*Lagerstræmia indica*) charcoal. Transparent lacquer is again applied with a piece of cotton-wool, and wiped off with soft paper, and the article is set to dry for 12 hours. Afterwards it is given a primary polish with an equal mixture of *Tō-no-ko* and deer's-horn ashes applied with a cotton cloth and a little oil. Next, a coating of *Yoshino* lacquer is applied with cotton-wool, wiped off with paper, and set to dry as before. At this stage only deer's-horn ashes, with a trifle of oil, are used for polishing. This process is repeated 3 times, and results in an exceedingly brilliant polish. Only hard woods are used for this kind of ware.

(*k*) *Red and Coloured Lacquers.*—For making best red and other coloured lacquers the first 22 processes are the same as in *Honji* (*a*). Next a mixture

of *Nashiji* (pure transparent lacquer) and vermilion, or the colour desired, is given to the article, which is thereupon set to dry. The remainder of the processes are identical with (*a*), except that *Yoshino* lacquer is substituted for "branch lacquer," and transparent varnish is used instead of *Rō* (black lacquer). For extra high-class work, instead of the thin coating of lacquer, which is wiped off again, a thick coating of transparent varnish is given, applied with a brush, and set to dry for about 35 hours, the further processes remaining unchanged. For second-rate articles, the colour is mixed with *Shuurushi* (transparent lacquer containing oil), and no after-polishing takes place. The article presents a brilliant surface, and the colour is better and brighter than in the best kind, but the surface is much less hard. Many processes are omitted for cheaper articles, as is the case in black lacquer, and less lacquer and more oil is used.

COLOURING MATTERS. — *Shu* (vermilion).—For red lacquer; used also mixed with gold-dust for shading.

Sei-shitsu (green lacquer).—A mixture of *Kiō* (chrome-yellow) and *Bero-ai* (Prussian blue).

Muras-aki-ko (purple powder). — A mixture of white-lead and *Tō-beni* (magenta roseine).

Benigara (red oxide of iron).—Sometimes used instead of vermilion.

In the district of Aidzu the light colours are produced to the greatest perfection, viz., yellow, green, and intermediate shades. In Tôkiô, though the same materials are used, the resulting colours are inferior and darker. In Aidzu no after-polishing takes place with coloured lacquers. The lacquer is applied like paint. Tôkiô is, however, best for black lacquer, as well as for such high-class red, &c., as are polished afterwards. These differences are attributed to some climatic influence.

The *Kioto*, so-called "black lacquer," shows a reddish-brown tinge. With the exception of Tôkiô, Kioto, Osaka, Kaga, Tsugaru, Wakasa, Nagova, Suruga, and Shidzuoka, and one or two isolated places, the method of smoothing with charcoal, and afterwards polishing, is not pursued. In Tsugaru and Wakasa neither flat nor raised gold lacquer is manufactured.

It should be mentioned that the plain lacquered articles are almost exclusively manufactured by one set of workmen, who supply the workers in gold lacquer with the articles ready for the application of the gold powdering, various patterns, &c.

The wholesale lacquer trade is in the hands of a few large merchants. In Tôkiô there are 2 houses only. These receive the crude lacquer from the producers as it arrives from the various districts, either buying it outright or making advances to the contractors, who are bound by the rules of the guild to deliver only to them. They sell it in quantities as required to the lacquer manufacturers, who prepare and refine the sap for the market, and these again retail the material to the lacquer-workers. The various processes that the lacquer undergoes in the hands of the manufacturers before retailing are kept secret, only the approximate mixtures being known.

That all lacquer, even that sold as pure lacquer, undergoes some adulteration, is rendered evident from the fact that, in accordance with a strange custom peculiar to the lacquer trade, the retail manufacturers sell even the smallest quantity at the same rate at which they buy it from the wholesale merchant.

GOLD LACQUER.—Among the tools and materials used in the manufacture are:—

Neji-fude.—Brushes made of rats' hair, used for tracing out the patterns, and for drawing the very fine lines, &c. The best are made of the long hairs from the backs of "ship rats," whose fur is not so likely to get rubbed.

U-no-ke-usuji-fude. — Fine brushes made of hares' hair. These are a little larger than rats'-hair brushes, and are used for filling in the patterns of the best articles, also for drawing outlines on common articles and ground work.

There are 2 sizes, *Dai* and *Sho*, used for drawing "large" and "small." There are, besides, 5 sizes of *Ji-nuri-fude* (grounding-brushes).

U-no-ke-hake.—A flat brush made of hares' hair, used for spreading the lacquer on large pieces of work. There are 2 sizes used.

Men-sō.—A stiff brush made of deer's hair, used for applying the *Sabi*, &c., in making raised gold lacquer. It is only employed for stiff mixtures.

Haké.—Flat brushes of human hair, for smoothing the lacquer after application, as in ordinary plain lacquer. There are 2 sizes used.

Bun-mawashi.—Compasses with fine brush attached for describing circles.

Ké-bo.—Brushes made from the long body-hairs of a horse, used for smoothing the fine gold powder and brushing off extra particles, as also for dusting. There are 4 sizes.

Fude-arai. — Brush-cleaner, made either of ivory or tortoise-shell. The brushes have to be very carefully cleaned, after using, with *Sesamum orientale* oil, to remove every trace of lacquer.

Tsutsu.—A quill from the wing of a swan or crane, over one end of which is stretched a piece of silk, used for scattering the gold-dust. There are 2 sizes used.

For applying *Nashiji* or *Hirame*, bamboo tubes of 3 different sizes are used, with silk of more open texture.

Saji.—Spoon, for putting the gold-dust into the quill or bamboo tube.

Hirame-fude.—A pointed piece of bamboo or other wood, used for picking up and applying *Hirame*, or the gold, or shell-squares.

Kujira-bera. — Whalebone spatula. Used for mixing the materials, and also when transferring the tracing on the paper to the article to be painted (process described farther on). The kind used is called island whalebone, and comes from China; that obtained from Japan is practically useless, being liable to split. Two sizes are used.

Hera. — Spatulas made of *Hinoki* (*Chamæcyparis obtusa*), smaller than those used by workers in plain lacquer. There are 3 sizes used for applying plain lacquer, and 3 for applying *Sabi*.

The tooth of a fish, ordinarily the *Tai* (*Cerranus marginalis*), fastened with lacquer on to a piece of bamboo, used for polishing such crevices as are too small to admit of charcoal, &c., being employed.

A piece of polished shell, used for smoothing the paper on which the pattern is drawn before tracing with lacquer.

Tsume-ban.—A palette, made either of tortoise-shell or buffalo-horn, worn on the left thumb.

Take-ban.—A small bamboo board, used when cutting the gold and silver foils into squares.

Gold and Silver Dust used for Ornamentation.—Of these there are several kinds, viz.:—*Yasuri-ko* or *fun* (file-powder), made of *Yaki-kin* (pure gold), *Koban-kin* (10 parts gold to $2\frac{6}{10}$ silver), and *Gin* (silver). There are 12 qualities of each, differing in fineness.

Besides these, there is an extra large kind, used for ground-work, called *Hira-me* (flat-eye). The coarsest filings, whether of pure gold, *Koban*, or silver, are taken and rolled out flat on an iron plate. Of *Hirame* there are 8 kinds each.

Next comes the sort called *Nashiji*, from its resemblance, when applied to the article, to the rind of a pear. *Nashiji* is used for ground-work, in making which pure gold, also *Koban-kin* (10 parts gold, $2\frac{6}{10}$ silver), *Jiki-kin* (10 parts gold, $3\frac{1}{10}$ silver), *Nam-kin* (10 parts gold, $3\frac{6}{10}$ silver), and silver of seven qualities of fineness each, are used.

Aka-fun (red powder) is vermilion mixed with pure gold, *Koban-kin*, and silver, for shading.

Kuro-fun (black powder) is camellia-charcoal powder mixed with pure gold, *Koban*, and silver.

Giyōn nashiji is the coarsest kind of *Nashiji* made, but it is little used, as it requires 7 or 8 coats of lacquer to be applied before it is covered sufficiently to stand polishing.

Keshi-fun.—This is the finest kind used; it is only made in pure gold and

Koban. This is made by mixing gold-leaf in liquid glue till it is reduced to an impalpable powder; water is then added, and when the gold sinks the liquor is poured away. This is repeated till all the glue has been got rid of.

Shaku-dō fun.—A mixture of 7 parts pure gold and 3 of copper powder.

Kana-gai.—Foil made of pure gold, *Koban*, and silver. It is made of 4 thicknesses in each quality, viz.: *Honneji*, *Chiu-neji*, *Usushu*, *Kime-tsuke*, the last being the thinnest.

Besides the above, there are several mixtures, as—

Kuri-iro-fun (chestnut-coloured powder).—A mixture of one-half gold-dust with powdered camellia-charcoal and vermilion.

Nedzumi-iro-fun (rat-colour grey).—A mixture of half silver and powdered camellia-charcoal, and a little vermilion.

In each case it is evident that several distinct shades can be obtained according as more or less colour is added to the gold and silver dust. It is a remarkable fact that no vegetable colours can be used with lacquer. They are all eaten up, as it were, by the lacquer, and disappear, which accounts for the very few variations seen in the colours of lacquer. The workmen have never been able to produce white, purple, or any of the more delicate shades.

Of late years, since cheap work has been introduced, the custom of using tin-dust has been adopted for making common *Nashiji*. It is manufactured of the same sizes as in gold and silver, and when plenty of gamboge is mixed with the lacquer to cover it, an inexperienced person might easily mistake it for gold when the ware is new; but it soon deteriorates. Burnt tin-dust is also sometimes used for under-coats in making cheap raised lacquer.

Mode of making Gold Lacquer.—(*a*) *Togi-dashi* (bringing out by polishing).—The article having been subjected to the first 22 processes, as described in making *Honji* (Class I.), is then treated as follows:—

The picture to be transferred to the article is drawn on thin paper, to which a coating of size made of glue and alum has been applied—that known as *Minogami* is best. The reverse is rubbed smooth with a polished shell or pebble, and the outline is very lightly traced in lacquer, previously roasted over live charcoal to prevent its drying, with a fine brush made of rats' hair. The paper is then laid, with the lacquer side downwards, on the article to be decorated, and is gently rubbed with a whalebone spatula wherever there is any tracing, and on removing the paper the impress may very faintly be perceived. To bring it out plainly, it is rubbed over very lightly with a piece of cotton-wool, charged with powdered white whetstone or tin, which adheres to the lacquer. Japanese paper being peculiarly tough, upwards of 20 impressions can be taken off from one tracing, and when that is no longer possible, from the lacquer having become used up, it only requires a fresh tracing over the same paper to reproduce the design *ad infinitum*. This tracing does not dry, owing to the lacquer used for the purpose having been partially roasted, as previously mentioned, and can be wiped off at any time.

The next process is to trace out the veining of the leaves, or such lines to which in the finished picture it is desired to give the most prominence, and these lines are powdered over with gold-dust through a quill. The qualities called *Mijin*, *Koma-kame-mijin*, and *Arajoku*, are generally used; either finer or coarser qualities cannot be used. The article is then set to dry for 24 hours in the damp press. The outline is now drawn carefully with a rat's-hair brush over the original tracing-line with a mixture of black and branch lacquer, called *Rō-sé*. The whole is then filled in with *Rō-sé* applied with a hare's-hair grounding-brush. Gold-dust of a slightly coarser quality than *Mijin* is scattered over the lacquered portion, and the article is set to dry for 24 hours. Another thin coating of *Rō-sé* lacquer is again given to the gold-powdered portions, and the article is set to dry for 12 hours. Next, a coat of

Rō (black lacquer) is applied over the whole surface of the article, which is set to dry for at least 3 days. It is then roughly ground down with *Magnolia* charcoal, the surface-dust being constantly wiped off with a damp cloth till the pattern begins to appear faintly. Another coating of *Rō* lacquer is then given, and the article is set to dry for 36 hours. It is again ground down with *Magnolia* charcoal as before, this time till the pattern comes well out. The ensuing processes are the same, from 28 to 33 inclusive, as in black lacquer (*Honji*) (*a*).

In making *Togi-dashi* on hard woods, transparent lacquer is used instead of *Rō*.

(*b*) *Hira-makiye* (flat gold lacquer). —The article having been thoroughly finished, either in black or red, &c., as already described under the head of *Honji*, Class I., and the following kinds, a tracing is applied to the surface as in *Togi-dashi*, the outline is carefully painted over with a fine brush of rats' hair, and then filled in with a hare's-hair brush, using *Shitamaki* lacquer (branch lacquer and red oxide of iron). Over this surface gold-dust (of the quality called *Aragoku* being generally used) is scattered with a brush of horse's hair (*Kebo*) till the lacquer will not absorb any more. The article is then set to dry for 24 hours. A thin coating is next applied over the gold, of transparent lacquer or *Yoshino* lacquer, and it is set to dry for 24 hours at least. It is then most carefully smoothed with camellia-charcoal, and finally polished off with *Tono-ko* and a little oil on the point of the finger, till the ornamented portion attains a fine polish. The veining of leaves and the painting of stamens, &c., of flowers, or such other fine work, is now done with a fine rats'-hair brush charged with *Ke-uchi* lacquer over which fine gold-dust (*Goku-mijin*) is scattered from a brush of horse's hair (*Kebo*), as before, and the article is set to dry for 12 hours. Some *Yoshino* lacquer is then applied to a piece of cotton-wool, and rubbed over the whole surface of the box or other article, and wiped off again with soft paper. It is set to dry for 12 hours, after which it is polished off with deer's-horn ashes and a trifle of oil. When very high-class work is desired, *Yoshino* lacquer, to which a little water has been added, is applied, and polished off a second time, and a very brilliant surface is attained.

More ordinary "flat gold lacquer" differs in the manufacture as follows:— The tracing is accomplished in the same manner, but *Shitamaki-nobe* lacquer (branch lacquer, red oxide of iron, and camphor) is used for filling in the pattern with a hare's-hair brush. The article is then set to dry in the press for 10 to 20 minutes, during which time the lacquer has begun to harden, and less gold will adhere. Then gold-dust (*Goku-mijin*) is applied with cotton-wool thinly, and the article is set to dry for 24 hours. The whole surface is then smeared over with *Yoshino-nobe* lacquer (*Yoshino* lacquer and camphor) on a piece of cotton-wool, and wiped off again with soft paper. The reason is that it is less trouble to smear over the whole surface thinly, and it is, moreover, not necessary to give a thick coat of lacquer to the decorated part, as the gold-dust has been very thinly applied. It is set to dry for 12 hours, and ground smooth with camellia-charcoal, and polished with powdered whetstone and oil on the point of the finger. The fine lines are then drawn with a rats'-hair brush charged with *Shitamaki* lacquer, and sprinkled with gold-dust (*Goku-mijin*) from a brush (*Kebo*), and the article is set to dry for 12 hours. The whole is again smeared with *Yoshino-nobe* lacquer and carefully wiped off again with paper, and set to dry for 12 hours. The article is then polished with powdered whetstone and oil on the point of the finger; and a second application of *Yoshino-nobe* lacquer with a little water, wiped off with soft paper, set to dry for 12 hours, and finally polished off with deer's-horn ashes and oil on the finger, finishes the operation.

Should it be required to make any dark spots or lines, such as birds' eyes,

or to draw human hair, &c., or other shading, this is done last of all with *Kuma*, "bear" lacquer, *Jō-hana*, and lampblack.

More common kind of Flat Gold-Lacquer Painting.—Instead of tracing the design in roasted lacquer, it is done with a mixture of powdered *Tono-ko* and water, and the impression is transferred to the articles with the whale-bone spatula as before. The reason for only using *Tono-ko* instead of lacquer is that the ground-work being inferior, it cannot be ground or smoothed afterwards, and the edges of the pattern would not be clean, nor stand out clear, should any lacquer get smeared outside the tracing-line. The outline is then filled in with *Shitamaki-nobe* lacquer with a coarse hares'-hair brush, and the article is set to dry for 20 minutes, or till a thin skin has formed on the lacquer, and then the half-dry surface is wiped over with cotton-wool charged with *Keshi-fun*, the finest gold-powder, and set to dry for 5 or 6 hours. The whole surface is then smeared with *Yoshino-nobe* lacquer, which is carefully wiped off again with soft paper, and the article is set to dry for $\frac{1}{2}$ day. The surface is then rubbed over gently with deer's-horn ashes and soft paper, to give it a polish, and to get rid of any of the last coat of *Yoshino-nobe* lacquer.

The fine lines are now drawn with a fine hare's-hair brush charged with *Shitamaki-nobe* lacquer, and the article is set to dry for 20 minutes or so; then *Keshi-fun* is applied with cotton-wool, and again set to dry for 5 or 6 hours. No further process takes place.

(c) *Taki-makiye* (raised gold lacquer).—The ground-work may be either black or coloured lacquer, *Nashiji* (pear basis of gold-dust), or the plain wood. The outlines of the pattern are transferred to the surface of the article in the same manner as in *Togi-dashi*, or "flat lacquer." The outline is then painted over with *Shitamaki* lacquer, and this is covered with powdered camellia-charcoal. If the outside is to be higher than the inside, a broad margin is painted and covered with charcoal-powder, leaving the centre untouched, and *vice versâ*; if the centre is to be higher, a faint line only is painted outside, and the inside is given a thickish coating, which is sprinkled with the charcoal-dust, and the article is set to dry for 12 hours. When taken out of the press, it is well dusted to get rid of any loose charcoal-powder, and is also washed, using a brush made of human hair (*Hake*) to clean out all the crevices and bring out the lines, &c. Some *Yoshino-nobe*, or "branch lacquer," with camphor, is now rubbed on with a piece of cotton-wool, and carefully wiped off with soft paper, and the article is set to dry for 12 hours. The raised parts are next carefully ground smooth with a piece of *Magnolia* charcoal, and a second coat of *Yoshino-nobe*, or of "branch lacquer," is applied as before, and dried.

If a well-raised pattern is required, 1, 2, or even 3 coats of *Sabi* ("branch lacquer" and *Tono-ko*) are applied, the outside edges being painted with a brush of deer's hair (*Menso*), and the inside lacquer applied with a small *Sabi* spatula, the article being set to dry after each application for 12 hours. For coarser work, it is then ground smooth with a white whetstone, and for finer work with a yellow whetstone. Over this some "branch lacquer," mixed with camphor, is rubbed with cotton-wool and wiped off with soft paper, and the article is set to dry for 12 hours.

If the pattern is not to be very high, the operations described in the last paragraph are omitted. A coating of *Taka-maki* lacquer is now given, the outside edges being carefully drawn with a rats'-hair brush, and the inside of the pattern filled in with a hares'-hair brush, and the article is set to dry for 36 to 48 hours. When taken out of the press, the surface is ground smooth with *Magnolia* charcoal, and then partly polished with camellia-charcoal on a cotton cloth. A little oil is now rubbed on, and a further polishing takes place with powdered "whetstone" on a cloth. Next, "branch lacquer" is rubbed over

the raised parts with cotton-wool and wiped off with soft paper, and the article is set to dry for 12 hours. It is next polished with deer's-horn ashes and a little rape-seed or sesamum oil applied on the point of the finger. Up to this point the formation of the pattern, whether mountains, waves, trees, men, birds, or animals, has been gradually completed.

If small squares of gold-foil (known as *Kiri kane*), or of coloured shell, are used in producing the pattern, they are now applied one by one on the point of a bamboo stick (*Hirame fude*), the spot where they are to be affixed having been smeared with a little *Rō-sé* lacquer to make them adhere. When all that is required has been affixed, a piece of soft bibulous paper is spread over the freshly done parts and pressed very carefully with the finger. This is to get rid of as much as possible of the *Rō-sé* lacquer that is not covered by the gold squares; the article is set to dry for 12 hours, and then the portion where the gold has been applied is gently polished with a little camellia-charcoal on the point of the finger, to get rid of the remainder of the *Rō-sé* lacquer. Shell patterns, and the coarser kinds of gold-dust that may be required, are applied in the same manner. The finer kinds of gold-dust are applied next over a coat of *Shitamaki* lacquer, and the article is set to dry for 12 hours. The remaining processes of polishing, drying, &c., are the same as in first-class "flat gold" lacquer.

For making raised-lacquer patterns on plain wood the whole surface is covered with tin-foil, stuck on with rice-paste, to keep the wood quite clean, and then the place only where the pattern is to come is cut out. In making all high-class lacquer, the edges of every article are pasted over with tin-foil to prevent their being rubbed or injured by the workman, and the same is done over each portion as it is finished.

The above is the ordinary method of making best raised lacquer, but from a glance at specimens it will be seen that there are such innumerable modifications of one process or another, according to the object to be produced, that it is manifestly impossible to do more than give the above cursory sketch. Nearly every piece of good lacquer made exhibits a specimen of each kind, viz., *Nashiji*, *Togi-dashi*, *Hira-makiye*, and *Taka-makiye*.

In making raised lacquer on inferior articles, the methods do not vary much from the good kinds; the work is merely less carefully executed. The saving is in the quantity and quality of the gold-dust used, and the absence of minute after-work, or in the use of silver and tin instead of gold-dust. In the very cheapest kinds, burnt tin-dust is used instead of charcoal over the first coat of *Shitamaki*. This is burnished bright, and over it a thin coating of lacquer and gold-dust is applied. At first it looks well, but loses its colour in a year or two. By using tin-powder the same height is attained in 1 coat that would necessitate at least 3 coats of lacquer and charcoal-dust. This kind of work is, however, only used for cheap articles for foreign export, and has been quite lately introduced.

(*d*) LACQUERING ON METAL.—For lacquering on iron or copper, brass or silver, the metal is smoothed and polished, and then given a coating of "crude lacquer" or "black lacquer"; the article is put over a charcoal fire, and the lacquer is burnt on to the metal till all smoke ceases to escape. The fire must not be too fierce, and the metal must not be allowed to get red-hot, or the lacquer turns to ashes. After the lacquer has burnt quite hard, the surface is rubbed smooth with *Layerstræmia* charcoal; these operations are repeated 3 or 4 times, till a good foundation of lacquer has been obtained. Then the same operations exactly are repeated as in making best "black lacquer," *Togi-dashi*, "flat gold lacquer," or "raised gold lacquer," only that the lacquer is burnt dry over the fire instead of being dried in the press. The lacquer is thus rendered quite hard and very durable. After the first 2 or 3 coats have been burnt

on, the subsequent drying processes can be carried on in the damp press, should it be so desired.

In winter, or when any article is required in a burry, the workmen sometimes put a charcoal fire in the press, over which a pan of hot water is placed. The steam which is thus generated helps to dry the lacquer in an hour or two, which would take 24 hours to harden ordinarily, but the lacquer thus dealt with loses its strength, and is never very hard. "Black lacquer" turns a rusty brown, the colouring virtue of the iron being apparently lost, and therefore this plan is never adopted for good work, and in second-rate work only for under-coats.

NASHIJI (Pear Basis).—This style of ornamentation, occupying an intermediate position between plain and ornamental lacquer, is treated of last. Till the opening of Japan to foreign trade, it was in the hands of workers in gold lacquer, but now for the most part all *Nashiji* on articles intended for exportation is applied by workers in plain lacquer. In making best *Nashiji*, as in *Toji-dashi*, the first 22 processes are identical with *Honji* (Class I.). A coating of *Rō-sé* is applied, and the gold-dust is sprinkled over the surface through one or other of the bamboo tubes, according to the fineness required. The article is set to dry in the press for 48 hours, and is then given a coating of pure transparent varnish. This is set to dry for 3 or 4 days, when it is roughly ground with *Magnolia* charcoal, and a second coat of transparent lacquer is given. The article is set to dry for 48 hours, and then ground with *Magnolia* charcoal till a perfectly smooth surface is obtained. Transparent lacquer is then applied with a piece of cotton-wool, and wiped off again with soft paper, and the article is set to dry for 24 hours. It is then polished with a mixture of *Tono-ko* and camellia charcoal powder and a little oil. Next, a coating of *Yoshino* lacquer is given, and wiped off with paper; the article is set to dry for 12 hours, and then it is polished with deer's-horn ashes and oil. This is repeated 3 times to finish the article.

The same processes are gone through when using silver instead of gold dust.

For cheap qualities, tin-dust is used, and the powder is scattered on glue immediately above a coating of *Kunoji* (whiting and glue). When the article is dry, it is burnished with *To-kusa* (*Equisetum*), and as soon as it presents a bright surface a coating of pure transparent lacquer, with gamboge, is given to it. It is set to dry for a day in the press, and ground with *Magnolia* charcoal. Over this a coating of *Shu-urushi* (transparent varnish containing oil) is applied, and another drying for 24 hours completes the process. (J. J. Quin.)

The best lacquered wares are dear on the spot. The Japanese are great connoisseurs of the art, and will not scruple to give prices which make European bidders draw back. The lacquer itself is comparatively high-priced. Its collection entails the expenditure of a good deal of time and trouble; the culture of the trees that furnish it is not properly understood or systematically carried out. In the province of Yoshino, 575 gr. is considered a fair yield for a well-grown tree. In the districts frequented by foreigners, the current prices of the several sorts of lacquer were (1875) as below :—

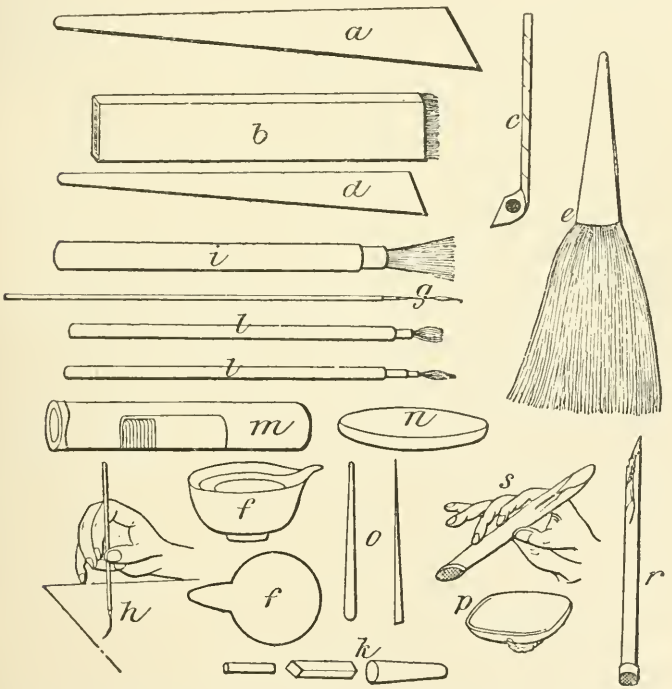
	Per lb.
Ki-urushi—red lacquer, as it comes from the tree . .	2*s.* 6*d.*—3*s.* 6*d.*
Seshime lacquer, for ground coats	2*s.* 3*d.*
Ro-iro-urushi — best black Japanese lacquer . . .	4*s.* 8*d.*
Red lacquer mixed with cinnabar	5*s.* 0*d.*
Nashiji lacquer for sprinkling with gold-leaf . . .	6*s.* 3*d.*
Haku-oh'to-urushi — golden lacquer	5*s.* 9*d.*

Dr. Wagener doubts whether Japanese lacquer could be advantageously used to any extent in European domestic architecture and cabinet-work. The process of lacquering is far more tedious and elaborate than graining, varnishing, and other decorative processes used in Europe. The labour required would be

greatly increased by its application to cabinet-work of European design in place of similar objects of Japanese model. Labour, too, is much dearer in Europe. In Japan, the weekly wages of a good lacquerer do not exceed 2*s.* to 3*s.* The hardness, durability, and brilliant metallic hues of these lacquers render them suitable for ornamenting fancy goods of all kinds in wood, paper, glass, porcelain, &c., a purpose for which they are very extensively employed in Japan. (*Monats. f. d. Orient.*)

The following details were communicated to 'La Nature' by the Japanese Commissioners at the Paris Exhibition, the accompanying illustrations (Fig. 134) being copied from a Japanese treatise on the subject written by Igarashi in 1570.

Fig. 134.



Objects in lacquered wood ornamented with paintings are termed in Japanese *Makiyé*, a word which signifies powdered or lacquered painting. The material best adapted for the work is *kinski*, the wood of a species of pine botanically termed *Retinispora obtusa*. The piece having received the desired form is plunged for an instant in boiling water, then wiped, and dried in the shade. It is next covered with lacquer—the word is here employed in the sense of varnish—and over this coating is sifted a layer of *jisun*, or unglazed pottery finely pulverized. Another powder is made of a schistose stone (*tonoko*), which is mixed

with *jisun* to form *kiriko*. This is diluted with lac varnish by means of a wooden spatula termed *urushi hera* (*a*). When the mass is perfectly homogeneous, the spatula is employed to lay it on as a groundwork on the object, which is then enclosed in a case, probably to protect it from dust, etc., and left quiet for 1½ days in summer and somewhat longer in winter. Then with a piece of the schist the entire surface is rubbed smooth.

A new paste of powdered schist and *seshime* (a kind of lac) without *jisun* is now prepared and applied, dried, and polished as before. Then the whole is rubbed with a wad of cotton soaked with lac, and carefully wiped with very fine paper, softened by long crushing in the hands. The object is next again enclosed and left to rest for ½ day. Still another preparation is then made, composed of a different kind of lac—*nuritate-urushi* and *shoyen*, or soot produced by the burning of pine knots rich in rosin. This is intimately mixed and filtered through paper. Into the mixture a flat brush, such as is shown in *b*, is dipped, and with this implement the object is covered with a smooth coating. Another drying of 2 days' duration, succeeded by polishing with *Honoki* charcoal, follows.

These preliminary operations constitute the *shita nuri* or sub-lacquering. The intermediate stage (*naka nuri*) consists simply in repeating the preceding painting with the soot mixture. Then begins the *uranuri*, or surface lacquering.

The object is first covered with *koero-urushi*, a very fine and brilliant varnish, greenish black in hue and purified by filtration. When dry, polishing by charcoal follows, and rubbing with schist is continued until not the least inequality on the surface is perceptible. At this point the schist powder is diluted with oil, and this is used as a polish until the surface becomes brilliant.

Now, on very thin closely made paper, the design which is to appear on the object is sketched. To transfer the marks to the work, a peculiar varnish called *yaki-urushi*, or burned lac, is employed, made as follows :—A band of paper is rolled in tube form *c*, an end being left unwound. A very small quantity of the *seshime-urushi* is placed on this end, and heated quickly to effervescence. Adding a very little red oxide of iron and camphor, the whole is carefully mixed and filtered. The varnish thus prepared warm does not become dry and friable. The paper, painted side up, is now attached to the object and rubbed with a whalebone spatula *d*. This causes the lines to be transferred to the prepared surface. A bit of tow is then used to dust on tin in powder, and the excess of the latter is removed by a very soft pencil *e*.

Painting the design is done with a lac called *shitamichi urushi*. This is a mixture of *seshime-urushi* $\frac{1}{10}$ part, *nashyi urushi* $\frac{4}{10}$, a small quantity of red oxide of iron of intensely red colour, and a little camphor. This is mixed and filtered 4 times; the more frequent the filtering the purer the material. The latter is then placed in a shallow cup *f*, and covered with a piece of permeable paper, which comes in contact with its surface and prevents its hardening by contact with the air.

The varnish thus prepared is laid on by means of a very fine pencil *g*, which is composed of rats' hair. The little finger is placed on the side of the object, so that the brush is held vertically and only the tip used, *h*. When this work is terminated, the design is covered with a priming powder by means of the brush shown in *i*, and the object is returned to its case to rest. This last powder consists of *Honoki* charcoal, mixed with $\frac{3}{10}$ sulphur. The whole is pulverized in a mortar and sifted through silk. On the next day, rubbing with *seshime-urushi* mixed with camphor, and another polishing with schist, follow.

"Rust finish" is the name given to the operation which produces the relief work for the figures. A mixture of *seshime* and schist powder is made pasty and applied with a spatula. The por-

tions not designed to stand in relief are removed with a brush. After drying, the low and raised portions are carefully polished with pieces of green schist, cut in forms either prismatic, conoidal, or cylindrical, *k*. The operation described at the end of the last paragraph is then repeated. On the next day, a soot varnish is made, and applied with a rats'-hair brush. After another 1½ days, a charcoal polishing succeeds, the charcoal being first rubbed smoothly on pieces of schist, and then applied. More polishing with schist powder and a rubbing with oil precede the painting of the lowered parts, for which purpose the *seshime* varnish, mixed with oxide of iron and camphor, is again used.

The designs are next painted with a rats'-tail pencil *l*, dipped in filtered oxide of iron, *seshime* varnish. Then, if, for instance, a peony is to be represented, 2 kinds of gold powder and a gold scale (*yasuriko*) are used for branches and stem. To represent rocks and stones, pieces of metal flaked, and made of still another kind of gold powder (*hanako*), are employed. How these metallic preparations are made will be described farther on. Having thus ornamented the work, 1½ days' rest is allowed, at the end of which time the rats'-tail brush is used to apply to the more delicate shades *yosheno-urushi* varnish, camphorated and filtered. Polishing with *Camellia japonica* charcoal follows; and this is a most delicate operation, requiring the longest practice, for there is constant danger of rubbing off the thin layer of metal. A little schist powder is scraped from a tender piece of the stone mixed with oil, and applied to the painting with the finger-tip, to produce a polish. The operation of gilding, &c., is then repeated, and then with a wad of tow the appropriate metallic colours for the objects depicted are applied. Next comes covering with *yosheno-urushi* varnish, wiping with cotton and paper, polishing with *shikido* (another schist) and oil, another application of camphorated varnish, then of the same mingled with water, another drying, and then a final polishing with powdered horn. The object is now uniformly brilliant, and the gold portions are finished.

To prepare the *kirikane*, or cut metal, a leaf of the same is spread upon a cylinder of bamboo *m*, and covered with paper. Then, by means of a razor, a number of fine equal bands are cut, a margin on each side being left intact. The leaf and paper are then turned so that the strips occupy a position perpendicular to that which they had at first. Carrying the razor in the former direction around the bamboo, the squares of metal leaf are detached and fall into a blackened saucer *n*. To pick up the pieces, a small stick of willow *o* is used, slightly moistened with saliva. Gold, copper, and silver are treated in this way.

The depolishing consists in removing the polish on certain parts of the object where portions of the design to be painted in colours fall. This is done by rubbing with *Honoki* charcoal powder, followed by retouching with the rats'-tail pencil. In the latter operation a cup of buffalo horn *p* is used, which is retained on the thumb by a cord. This cup contains a lacquer, *seshime* varnish, and iron oxide, filtered 5 times through paper. Then the proper powder to give the colour is placed in a goose-quill *r*, at the end of which is a very fine sieve, through which the powder is shaken in clouds over the wet lacquered part, the excess being removed with a soft brush. The object is then left to dry.

The powders and leaves of metal used are always in harmony with the subject. To paint a river, for example, the shores are boldly traced with the rats'-hair pencil, using the point to indicate the water. Then with the feather a certain coloured gold powder is sifted on, then a powder of different colour, and, finally, here and there fragments of gold-leaf are inserted. For a black ground a smoke-black varnish is used, and the gilded parts are covered with a transparent varnish. After 5 or 6 days' drying, the black parts are slowly polished with powdered *Honoki* char-

coal, then the gold is polished with camellia charcoal, then with horn powder, then rubbed with a wet cloth, then with a dry one. The piece thus prepared is covered with black varnish again, the design is rubbed and dried, and the piece is put away for the night. Next day schist powder and oil are applied, and more rubbing with paper is done. On the following day the finger is the rubbing instrument, and another polishing with horn powder finishes the operation.

A grey groundwork is applied after the sub and intermediate lacquering above described is finished, the parts being previously depolished by the goose-feather apparatus, held as shown in *s*, and rubbed gently on the surface, so as to scatter the metallic powder. The white flakes called *shiroq-irshi* are gently passed over the parts thus gilded. *Nashyi-urushi* varnish mixed with camphor is then laid thinly on; polishing with camellia charcoal follows, then drying, and then another coat of varnish; after another drying, a number of small prisms of camellia charcoal are polished on schist wrapped in paper, and are rubbed over the surface till the groundwork shows. Then follows a series of varnishing and horn-powder polishing similar to that already described.

Japanning and Japans.—(*a*) When finished wood, papier-mâché, composition, or metals are varnished in the usual manner and left to dry in the air, the drying is in most cases imperfect, and the coating more or less uneven. If the surface thus varnished is heated for some time to a temperature of 250° to 300° F. (121° to 149° C.), or higher, it is found that the whole of the solvent or vehicle of the gums or resins in the varnish is soon driven off, and the gummy residue becomes liquefied or semi-liquefied, in which state it adapts itself to all inequalities, and if the coating is thick enough presents a uniform glossy surface, which it retains on cooling. This process of drying out and fusion secures a firm contact and adhesion of the gums or resins to the surface of the substance varnished, and greatly increases the density of the coating, which enables it to resist wear and retain its gloss longer. This process of hardening and finishing varnished or lacquered work by the aid of heat constitutes the chief feature of the japanner's art. In practice the work to be japanned is first thoroughly cleansed and dried. If of wood, composition, or other porous material, it is given while warm several coats of wood-filler, or whiting mixed up with a rather thin glue size, and is, when this is hardened, rubbed down smooth with lump pumice. It is then ready for the japan grounds. Metals as a rule require no special preparation, receiving the grounds directly on the clean dry surface. In japanning, wood and similar substances require a much lower degree of heat and usually a longer exposure in the oven than metals, and again a higher temperature may be advantageously employed where the japan is dark than when light-coloured grounds are used: so that a definite knowledge of just how much heat can be safely applied and how long an exposure is required with different substances and different grounds can only be acquired by practical experience. The japanner's oven is usually a room or large box constructed of sheet metal, and heated by stove drums or flues, so that the temperature—which is indicated by a thermometer or pyrometer hung up inside, or with its stem passing through the side-wall midway between the top and bottom of the chamber—can be readily regulated by dampers. The ovens are also provided with a chimney to carry off the vapours derived from the drying varnish, a small door through which the work can be entered and removed, and wire shelves and hooks for its support in the chamber. The ovens must be kept perfectly free from dust, smoke, and moisture.

A good cheap priming varnish for work to be japanned consists of:—

Shellac (pale)	.. ..	2 oz.
Rosin (pale)	.. ..	2 ,,
Rectified spirit	.. ..	1 pint.

Two or three coats of this are put on the work in a warm dry room. A good

black ground is prepared by grinding fine ivory-black with a sufficient quantity of alcoholic shellac varnish on a stone slab with a muller until a perfectly smooth black varnish is obtained. If other colours are required, the clear varnish is mixed and ground with the proper quantity of suitable pigments in a similar manner: for red—vermilion or Indian red; green—chrome-green, or prussian blue and chrome-yellow; blue—prussian blue, ultramarine, or indigo; yellow—chrome-yellow, &c. But black is the hue commonly required. The following are good common black grounds:—

(1) Asphaltum .. .. .. 1 lb.
Balsam of capivi .. 1 ,,
Oil of turpentine .. q.s.

The asphaltum is melted over a fire, and the balsam, previously heated, is mixed in with it. The mixture is then removed from the fire and mixed with the turpentine.

(2) Moisten good lamphlack with oil of turpentine, and grind it very fine with a muller on a stone plate. Then add a sufficient quantity of ordinary copal varnish and rub well together.

(3) Asphaltum .. .. .. 3 oz.
Boiled oil .. .. .. 4 qt.
Burnt umber .. .. 8 oz.
Oil of turpentine .. q.s.

Melt the asphaltum, stir in the oil, previously heated, then the umber, and when cooling thin down with the oil of turpentine.

(4) An extra fine black is prepared from—

Amber .. .. .. 12 oz.
Asphaltum (purified) 2 ,,
Boiled oil .. .. .. ½ pint.
Rosin .. .. 2 oz.
Oil of turpentine .. 16 ,,

Fuse the gum, rosin, and asphaltum, add the hot oil, stir well together, and when cooling add the turpentine.

A white ground is prepared from copal varnish and zinc white or starch. Large japanners seldom make their own varnishes, as they can procure them more cheaply from the varnish-maker.

From 1 to 6 or more coats of varnish are applied to the work in japanning, each coat being hardened in the oven before the next is put on. The last coat in coloured work is usually of clear varnish without colouring matters, and is in fine work sometimes finished with rotten-stone and chamois-leather. For ordinary work, the gloss developed in the oven under favourable conditions is sufficient. (*Scient. Amer.*)

(*b*) Melt 50 lb. Naples asphaltum and 8 lb. dark gum anime, boil for about 2 hours in 12 gal. linseed-oil; then melt 12 lb. dark gum-amber and boil it with 2 gal. linseed-oil; add this to the other, and add dryers. Boil for about 2 hours, or until the mass when cooled may be rolled into little pellets. Withdraw the heat, and thin down with 30 gal. turpentine. During the boiling the mass must be constantly stirred to prevent boiling over.

(*c*) Japan for Tin Lantern. — The following are the proportions for black japan: asphaltum, 1½ oz.; boiled linseed-oil, 4 pints; burnt umber, 4 oz. Heat till well mixed, and when cool add turpentine till of a proper consistence.

(*d*) Re-japanning Tea-trays. — It is no easy matter for an amateur to japan a tea-tray. In the first place, if the tray is scratched or chipped, burn off the japan; if it is not scratched, cut it down with pumice and water (ground pumice) until it is smooth. Then get some brown japan (Pontypool varnish) —say, 2 gills—and with a camel-hair brush lay it over evenly. See that no hairs get on; if they do, pick off with a knife. Then put in a place free from dust to dry, which will take about 4 days, unless you have an oven. A common oven will do; but take care of dust. When you cannot leave any marks of your fingers, it is hard and ready for rubbing with pumice again, and adding another coat; 3 coats altogether will do. Then pumice, and finish with rotten-stone and water, or putty-powder. Be careful to rub all one way, not across nor roundabout. Then take and rub quickly with the heel of the hand to burnish it. To ornament the same:— If with transfer pictures, varnish the part neatly and very thinly (as it leaves

a mark when too much is put on) with copal varnish. Then let it stand for ½ hour until it is set or nearly dry. Put on the transfer, press it with the hand, take sponge and hot water and dab it lightly; in 3 minutes slide the paper off. Then draw the sponge across the picture to take the gum off, or it will appear a network of cracks in a day or two. When dry, varnish the picture parts only, as the black will stand longer than varnish.

(*e*) Japanning Tin.—The first process with the tea-tray, which is made of sheet-iron, is to scour it well with a piece of sandstone, which process removes all the scales of iron and makes the surface perfectly smooth. It is then given a coat of vegetable black, which must be mixed with black tar varnish, and thinned with tar spirits and well strained: only a small quantity of varnish, as this coat may dry dead. The article is then put into a stove to harden. This stove is nothing more nor less than a large oven; large of course where a great quantity of work is put in at one time. The heat must be as even as possible all over the heated space, and must be free from dust. Temperature must not be much, if any, under 212° F. (100° C.), the articles to remain in this temperature 10 to 12 hours; when taken out of the stove, to be allowed to get cold. They then receive a coat of black tar varnish, which must in no case be thinned except it be so thick as to be quite unworkable; and in that case tar spirits should be used sparingly. A stiffish bristle brush with short bristles should be used, such as are generally bound with iron ferrules. The varnish is distributed evenly all over the surface, and must be put on so sparingly that it cannot "run," as japanners say, which it is sure to do immediately it gets warm, particularly on upright articles, if too much is put on. Two coats of this varnish on the top of the vegetable black is very often sufficient when done by an expert hand, but a third coat improves the work, and very frequently is indispensable; 10 to 12 hours' hardening is requisite between the coats. It is likewise necessary to rub down the small lumps which will appear after each coat with a piece of pumice, first made flat by rubbing it on a slab of slate. Keep dipping the pumice in water. This rubbing-down must be executed very lightly, or the smooth parts will be scratched. If the article is to be decorated with burnished gold, the first process after coming out of the stove the last time is to "rough" it. This is done with very fine pumice sand, applied with some kind of corded or roughish material. Russell cord does very well. Jean is the material mostly used. The process is very laborious, as it requires all the pressure that can be employed, and that, too, for some considerable time. It is part of the polishing. When the surface has been made level by this, the next thing is to go through the same again; but this time, instead of using sand and the cutting material, black or soft rotten-stone must be used, with flannel or cloth kept well wetted, as before. This makes the surface exceedingly smooth, and ready to be brightened up into a fine polish by rubbing the sand up and down. The person so employed has to keep rubbing the dry soft hand into powdered white rotten-stone, and also occasionally moistening the hand by placing it on a wet cloth for the purpose. The polish soon comes up under a practical hand. All these processes are performed by women and girls. It takes months of practice in this polishing before the hand obeys the intellect. The work now passes to the ornamenter. After he has put on his ornaments of gold and colour, it is placed in a stove at only a few degrees of heat, as much heat would destroy his work. When dry, that part only of the article which is covered with ornament receives a coat of copal polishing varnish. This varnish does not improve the appearance, but is necessary to preserve the decoration. No polish or varnish can equal black varnish, which is about a fourth the price of copal. This varnish is put on with a flat camel-hair brush, and will harden in a heat of about 100° F. (38° C.)

in 4 hours. If put in too great heat, it will turn colour, and completely spoil the work. It is now ready for "finish" polishing, which consists of the rotten-stone process again, and handing up as before, and last of all, a few spots of oil are used, with a sprinkling of water, and this is called oiling off. It requires great dexterity, or instead of adding to the lustre with the oil it will completely dull the surface. There are plenty of goods that do not go through all these processes and yet look fairly well; such, for instance, as grocers' canisters and numerous other articles. These, as soon as they have received the second coat of black varnish, are taken straight to the ornamenter without being "ronghed" or polished, and if the varnish has been put on well and kept free from dust they look very well. When no polishing is done either before or after the ornamenting, the article is frequently covered all over with the copal varnish coat. The only safe way of obtaining the proper varnishes is to get them from those who supply japanners. The best black tar varnish obtainable can be had at 4*s.* 6*d.* per gal. The best oil copal polishing varnish is 16*s.* per gal., inferior qualities as low as 6*s.* or 7*s.* Oil copal polishing varnish at 12*s.* should be good enough for most purposes. When tin goods are to be japanned, the only preparation necessary is to clean off all grease spots with a piece of clean rag dipped in turpentine; and as to heat, when it is not too hot to disturb the solder, it will not hurt the black varnish, provided it is put on sparingly. If not, the varnish will shrivel. The finish upon grocers' canisters may easily be obtained, as there is nothing on them but good stoving and varnishing—no polishing. Coloured surfaces are ground in turpentine in a mill, or on a stone slab, and mixed with mixing varnish, which costs about 6*s.* per gal. If an emerald-green ground is required, some let the first coat be of white-lead mixed with varnish, and this is followed by 2 coats of the emerald-green without any white in it. The coat of white gives to the green a solidity which could not be obtained otherwise. A moderate heat is required, as these varnishes will not become hard without heat, but in no comparison to the heat, nor the time required, for black varnish. A vermilion ground is sometimes first coated with orange-red, and one coat of vermilion on that should be sufficient. When the last coat is dry or hard, the whole surface should be well rubbed down with fine pumice sand, which can be purchased from oil and colour shops; but it must be fine, and if necessary dusted through fine muslin. What is called a "bob" must be made of a piece of jean, large enough to hold in the hand conveniently, and this must be dipped into water and then into the sand; this rubbed vigorously up and down the work will make it quite smooth. Use freely of the water, but moderately of the sand. Afterwards wipe all off cleanly with a wash-leather; and the surface will be found to be dull but smooth. Exactly this method is used likewise for black varnished surfaces. The work is now ready for ornamenting, if any ornamenting is to be done. If not, it is ready for varnishing with the clear varnish (not mixing), which will at once brighten the surface which has had to be dulled in the operation of smoothing it. (*Eng. Mech.*)

(*f*) All wood-work intended to be japanned must be prepared with size, and some coarse material mixed with it, to fill up and harden the grain of the wood (such as may best suit the colour intended to be laid on), which must be rubbed smooth with glass paper when dry. In cases of accident, it is seldom necessary to re-size the damaged places, unless they are considerable. Be very careful, in japanning, to grind your colours smooth in spirit of turpentine; then add a small quantity of turpentine and spirit varnish; lay it carefully on with a camel-hair brush, and varnish it with brown or white spirit varnish, according to the colour. The colours required are flake-white, red-lead, vermilion, lake, Prussian blue, patent yellow, orpiment, ochres, verditers, vandyke-brown, umber, lampblack, and

siennas raw and burnt. With these you may match almost any colours in general use in japanning. For a black japan, it will be found sufficient to mix a little gold-size with lamp-black; this will bear a good gloss without requiring to be varnished afterwards. To prepare a fine tortoise-shell japan ground by means of heat, take 1 gal. good linseed-oil and ½ lb. umber; boil them together till the oil becomes very brown and thick; strain through a coarse cloth, and set again to boil, in which state it must be continued till it acquires a consistence resembling that of pitch; it will then be fit for use. Having thus prepared the varnish, clean well the substance which is to be japanned. Then lay vermilion tempered with shellac varnish, or with drying-oil very thinly diluted with oil of turpentine, on the places intended to imitate the more transparent parts of the tortoise-shell. When the vermilion is dry, brush the whole over with black varnish tempered to a due consistence with the oil of turpentine. When set and firm, put the work into a stove, where it may undergo a very strong heat, which must be continued a considerable time; if even 3 weeks or a month, it will be the better. This tortoise-shell ground is not less valuable for its great hardness, and enduring to be made hotter than boiling water without damage, than for the superior beauty and brilliancy of its appearance. (*Painter, Gilder, and Varnisher's Companion.*)

Metallic surfaces, Lacquering.—Following are miscellaneous recipes for lacquering metallic surfaces of all kinds. (1) For gold: 1 gal. alcohol, ½ lb. turmeric; macerate for a week, then filter, and add 2 oz. gamboge, 6 oz. shellac, 1¾ lb. gum-sandarach; dissolve in warm bath, and add 1 qt. common turpentine varnish. For red lacquer use 1½ lb. annatto instead of the turmeric, and 8 oz. dragon's blood instead of the gamboge. (2) Pale: alcohol, 8 oz.; turmeric, 4 dr.; dragon's blood, 4 scr.; red sanders, 1 scr.; hay saffron, 2 scr.; shellac, 1 oz.; gum-sandarach, 2 dr.; gum-mastic, 2 dr.; Canada balsam, 2 dr.; dissolve, and add 1½ dr. spirits of turpentine. (3) The following is an excellent lacquer for brass:—Seed-lac, 12 oz.; copal, 4 oz.; dragon's blood, 80 gr.; extract of red sanders-wood, 50 gr.; saffron, 70 gr.; pounded glass, ½ lb.; spirits of wine, 2 qt. This is very durable. (4) Pale: 1 gal. methylated spirits of wine, 5 oz. shellac, 4 oz. gum-sandarach, and 1 oz. gum-elemi; mix in a tin flask, and expose to a gentle heat for a day or two; then strain off and add ½ gal. spirit to the sediment, and treat as before. (5) Pale gold: 1 gal. methylated spirits of wine, 10 oz. seed-lac bruised, and ½ oz. red sanders; dissolve and strain. (6) A paste is made of finely-pulverized quartz, carbonate of potash (or oxide of lead) and water, according to the colour required. A thin coat of this is applied with a brush to the object, which is then placed in a muffle, and heated to 1495° F. (811° C.). The articles emerge covered with a sort of polished glass, which resists blows, and which does not split nor scale off, while it serves perfectly to protect the metal against oxidation. (7) Petroleum essence, 1 lb.; boiled linseed-oil, ½ lb.; to be mixed cold. Metallic plates prepared for lithography, &c., are brushed over with this varnish (applied cold); when dried by heating, it has a golden yellow tint. (*Bul. Soc. Chim.*) (8) Green Varnish for Metals.—Finely pulverized gum-sandarach or mastic (the latter, however, is too expensive for some uses) is dissolved in strong potash lye until it will dissolve no more. The solution is diluted with water, and precipitated with a solution of a copper salt, either sulphate or acetate. This green precipitate is washed, dried, and dissolved in oil of turpentine, producing a fine green varnish which does not change under the effect of light, and will be especially useful for ornamental iron-work. (*Industrie Blätter.*) (9) Green Transparent Varnish.—Grind a small quantity of Chinese blue with double the quantity of finely powdered chromate of potash (it requires most elaborate grinding); add a sufficient quantity of copal varnish, thinned

with turpentine. The tone may be altered by more or less of one or the other ingredients. (10) Green Bronze Liquid. — 1 qt. strong vinegar, ½ oz. mineral green, ½ oz. raw umber, ½ oz. sal-ammoniac, ½ oz. gum-arabic, 2 oz. French berries, ½ oz. copperas; dissolve the whole in a pipkin over a gentle fire, allow to cool, and then filter. (11) Green Lacquer. — Mix 5 oz. shellac, 6 oz. turmeric, 4 oz. gum-sandarach, and 1 oz. each gum-elemi and gum-gamboge in 1 gal. methylated spirits; expose to a gentle heat, strain, add ½ gal. spirit to the sediment, and treat as before. (12) Gold-coloured Lacquer for Brass Watch-cases, &c.—6 oz. seed-lac, 2 oz. amber, 2 oz. gamboge, 24 gr. extract of red sanders-wood in water, 60 gr. dragons'-blood, 36 gr. oriental saffron, 4 oz. powdered glass, 36 oz. pure alcohol. The seed-lac, amber, gamboge, and dragons'-blood must be pounded very fine on porphyry or clean marble, and mixed with the pounded glass. Over this mixture is poured the tincture formed by infusing the saffron and the sanders-wood extract in the alcohol for 24 hours, then straining. Metallic articles that are to be covered with this varnish are heated, and, if they admit of it, immersed in packets. (13) For philosophical instruments: 1½ oz. gamboge, 4 oz. sandarach, 4 oz. elemi, 2 oz. best dragons'-blood, 1½ oz. terra merita [terra merita is the root of an Indian plant; it is of a red colour, and much used in dyeing; in varnishing, it is only employed in the form of a tincture, and is particularly well adapted for the mixture of those colouring parts which contribute the most towards giving metals the colour of gold; in choosing it, be careful to observe that it is sound and compact], 4 gr. oriental saffron, 2 oz. seed-lac, 6 oz. pounded glass, 40 oz. pure alcohol. The dragons'-blood, gum-elemi, seed-lac, and gamboge are all pounded and mixed with the glass. Over them is poured the tincture obtained by infusing the saffron and terra merita in the alcohol for 24 hours. This tincture, before being poured over the dragons'-blood, &c., should be strained through a piece of clean linen cloth, and strongly squeezed. If the dragons'-blood gives too high a colour, the quantity may be lessened according to circumstances. The same is the case with the other colouring matters. This lacquer has a very good effect when applied to many cast or moulded articles used in ornamenting furniture.

Optical Work, Lacquering.— If an article has been lacquered before, that lacquer must, in the first place, be removed, and the article afterwards carefully cleaned and polished. When the brass has not been lacquered before, it must receive before lacquering the highest possible finish and polish, if it is desired to make a fine job. This is done by taking out the marks of the file with finer and finer sorts of emery-paper or cloth, then polishing with rotten-stone or oil, and giving the article, after this has been cleaned off, a final touch with a buff-stick and crocus powder. The article must be carefully wiped clean, and care taken that it is not touched with the fingers after this has been done, as these would leave a greasy mark. Care must be taken at every step to invariably lay the successive strokes of the emery-cloth or paper and polishers in the same direction. When the desired degree of polish has been attained, a quantity of lacquer is poured into (say) an egg-cup, which is a very convenient receptacle for the purpose. A fine flat camel-hair brush is taken, and the article being gently warmed and held on the left hand, a small quantity of the lacquer is taken up on the brush, and the brush is drawn over the brass with straight strokes, always, if possible, in the same direction. The article may generally be held by screwing a piece of wire into some hole in it, and holding the wire with a small hand-vice. As many coats of the lacquer as desired may be given by keeping the brass hot; the degree of heat is an important element in the success of the operation. Holtzapffel says it must not be warmer than boiling water; but so far as my experience

goes, I should say the heat of boiling water would be too great. Considerable skill is required in lacquering well, and that skill can only be attained after a good deal of experience. The great secret of lacquering for beginners, at all events, is to take as little as possible of the lacquer at a time on the brush, have the article *perfectly* clean, a good brush with no loose hairs in it, and not make the article too hot.

Now as to lacquers. There are a great variety of them. As a rule, English brass-work is covered with a very pale lacquer containing almost no colour; while, on the contrary, Continental lacquers contain too much colour. Wray's is a very fine specimen of lacquering. It has, however, in it a fugitive colouring material, and when a certain time elapses, the brightness leaves it. Zeiss's, again, has a great amount of colour in it. Wray's looks well when new; but it very soon fades, and the colour becomes bad. The simplest and best pale lacquer, Holtzapffel says, is made of shellac and spirits of wine only, in the proportions of about ½ lb. of the best pale shellac to 1 gal. of spirit. It is, he says, required to be as clear and bright as possible, and is always made without heat by continuous agitation for 5 or 6 hours. If not clear, it may be filtered, and should be kept out of the influence of light. It may be coloured for yellow tints with turmeric, Cape-aloes, saffron, or gamboge; and for red tints with annatto or dragons'-blood.

What I have described is the process adopted for lacquering the outside of photographic lens mounts, or all those portions of the brass-work where the light does not pass. The inside of the mounts, however, is treated in a totally different way. We must have, where light passes, a surface as nearly dead black as can be got. This is obtained, in the inside of the tubes, by mixing finely triturated lampblack with the lacquer used for the outside, and applying the black lacquer in one or more coats with heat to the inside of the tube. The result is a finely grained black surface which reflects no light. As soon as the surface has received one or two coats, no more must be given, as the repeated application of the lacquer would make the surface glossy—the very thing which it is wished to avoid. This method of blackening the brass does excellently for all portions which are not to come into contact with the fingers; but wherever the brass requires to be handled, we must have recourse to something different from lampblack. One of the modes adopted for that purpose is to bronze the articles. There are various ways of doing this. Every one must be familiar with the ordinary greenish colour of gas-fittings which are bronzed. The article is first thoroughly cleansed from all grease, and then dipped in vinegar or a strong solution of sal-ammoniac, or sal-ammoniac and vinegar mixed in the proportion of 1 to 3 oz. of the sal-ammoniac to 1 pint of vinegar. Holtzapffel says a quick bronze is made with 1 oz. corrosive sublimate dissolved in 1 pint vinegar. The best and most rapid, however, of all the bronzing liquids, is the nitro-muriate of platinum, called "chemical bronze." It is known in the shops as the ter-chloride of platinum. This produces the colour very readily. All these methods, however, merely give a bronze tint, and not the black surface we should like to get. If I take a piece of clean brass, and touch it with the platinum solution, the bronze effect is almost instantly produced; but it does not, in my hands, produce black. The bronzing process is invariably used with all articles put together with soft solder. The method I am about to describe requiring a considerable amount of heat, the articles must be without any soldered joints. When I first began to "work in brass," a great many years ago, at the lathe, I experienced much difficulty, sometimes not being able to give some parts of the articles I produced a sufficiently dead-black surface, such as the setting of lenses, lens-stops, and such like.

Merely bronzing in such a case will not do, and lacquer and lampblack is worse. I became acquainted with an Edinburgh optician who had been taught

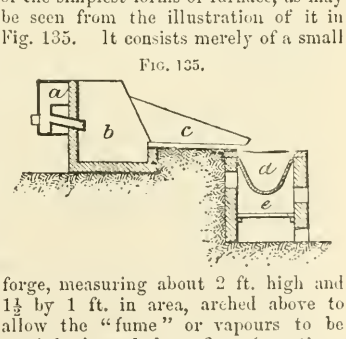
his knowledge of brass-work finishing for philosophical instruments in the workshop of the late John Adie; he knew no method except bronzing. At that time he had a large business in the sale of the student's Nachet and Hartnack microscopes, the brass stages of which are, perhaps, the most beautiful specimens of blackened brass which can be produced. We wrote to Nachet, and asked him how it was done, and, I think, he replied that it was done by nitrate of silver. We tried that, and failed. There was nothing for it but to fall back upon the bronze again. Some time after, when the Rev. J. B. Reade described his microscope kettle-drum condenser in the *Proceedings* of the Royal Microscopical Society, he incidentally mentioned that those portions of the mount which it was necessary to blacken were blackened by nitrate of copper. My friend and I tried it almost as soon as I had read it, and we succeeded at once in producing a black surface which was everything we wished. I prepare the solution by dissolving copper wire in nitric acid, weakened by adding, say, 3 or 4 parts of water to 1 of acid. The article to be blackened is heated pretty hot, and then dipped into the solution; it is then taken out, and heated over a Bunsen burner or spirit-lamp. When the article is heated to the proper temperature, the green colour of the copper first appears, and as the heat is increased, the article becomes of a fine dead black. It is not necessary to lacquer it. It seems better, to my thinking, to let it alone, just giving it a good brushing to remove the dust, and it may be considered finished. If, however, it gets a single coat of lacquer, the colour becomes blacker, and if there is not sufficient put on to make the surface glisten;—too much lacquer, however, invariably produces an objectionable polished surface. (W. Forgan.) See also Workshop Receipts, pp. 74–76.

Lanthanum.—This is another member of the cerium group of metals. About 5½ per cent. of its oxide is present in orthite, 3½ in cerite, and 3¼ in gadolinite. Its separation from the associated metals is a very difficult matter. Mosander obtained the metal as a grey powder by heating the chloride with potassium; and Hillebrand and Norton procure it in globules by electrolysing the fused chloride. The metal oxidizes slowly in water and in nitric acid, whether concentrated or dilute; it dissolves in hydrochloric and in dilute sulphuric acid, but not in cold concentrated sulphuric acid; its sp. gr. is 6·163, and its colour is iron-grey; it takes a high polish, but soon tarnishes; it burns brightly in a flame, and ignites in chlorine gas; finally, it can be hammered into foil, but not drawn into wire.

Lead.—The two most important sources of metallic lead are its natural sulphide (galena) and its carbonate (white lead ore). The ore, when mined, is hand-sorted free from refuse, broken small, and washed clean. It is then treated by one of the following methods for the extraction of the metal.

Ore-hearth.—The ore-hearth or Scotch furnace is a form of blast-furnace well suited for the treatment of ores containing little silica; here it is used on poor ores, but on the Continent (Przibram in Bohemia and Pesey in Savoy) it is employed on the richer kinds. It is one of the simplest forms of furnace, as may be seen from the illustration of it in Fig. 135. It consists merely of a small

Fig. 135.



forge, measuring about 2 ft. high and 1½ by 1 ft. in area, arched above to allow the "fume" or vapours to be carried through long flues (sometimes upwards of 3 miles), wherein much oxide and sulphate of lead are condensed and recovered. The operation involved is simply oxidation of the sulphur com-

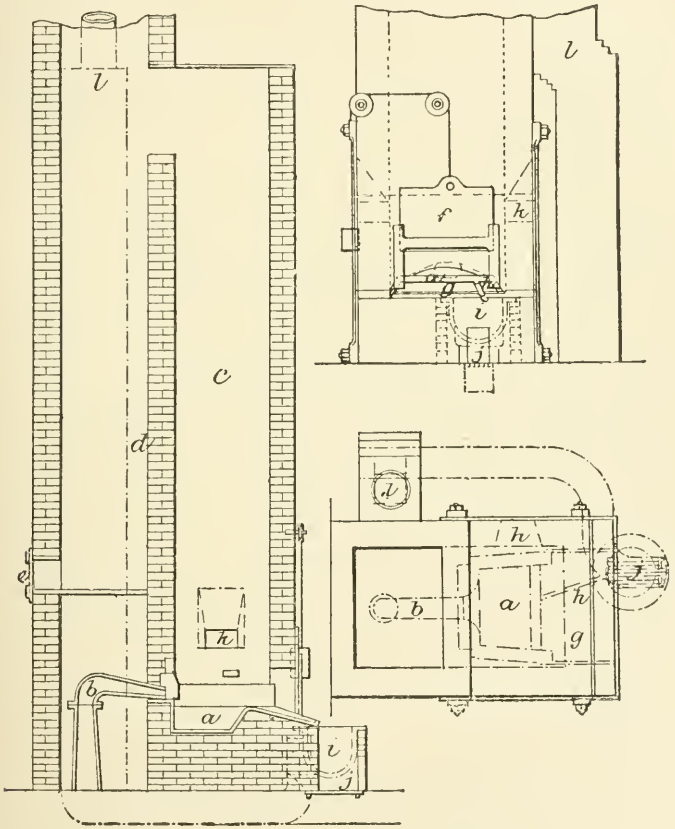
bined with the lead, thus: $PbS+2O=Pb+SO_2$. The temperature necessary is therefore but small, and must never rise to such a point as to endanger fusion of the sulphide. The ore is previously spread on the bed of a reverberatory furnace in charges of about ½ ton, and gently roasted for some 8 hours with constant stirring. By this step much of the antimony and part of the sulphur are expelled, and the hot roasted ore is raked out into a tank of water, where it breaks up. Thus reduced in size, it is charged into the ore-hearth, whose sides and floor are lined with cast-iron plates, leaving an opening about 1 ft. high in front; this is occupied by the "work stone," a sloping iron plate, upon which the materials are drawn for inspection as the operation proceeds. Quantities of 25 to 30 lb. of ore are introduced at a time, and the draught is stopped every 10 minutes to rake out half-fused and exhausted matters, and to replenish the fuel and mineral. The draught enters at *a*, about midway down the back of the furnace *b*; *c* is the work stone; *d* is a cast-iron pot which catches the molten lead running from the floor of the hearth, and heated by a separate fire *e*.

This plan is apt to entail considerable loss of metal by vaporization and to occasion unpleasant fumes; but it is eminently simple, the low temperature renders the metal free from hard impurities, and requires but little fuel, which may be of the poorest description. In Scotland, peat blocks are used, the furnace being filled with them at starting. The first charge of ore is "browse," the mixture of cinders and half-fused ore from a previous operation; this is immediately preceded by a little coal, to momentarily increase the heat. At short intervals the charge is withdrawn on to the work stone for manipulation. Shining glassy lumps of "grey slag" (a mixture of silicates of lead and lime) are picked out for treatment at a higher temperature in the "slag hearth" (p. 342); and the cleansed browse is returned into the furnace. A little lime is added to regulate the readiness with which the browse fuses, according to circumstances. Each time a new charge is introduced, the entrance to the blast-pipe is closed to exclude dust.

According to Dr. Ballard, the ore hearth appears to be the only plan adopted for lead-smelting in Scotland, Northumberland, Durham, and Cumberland. The form used by Cookson and Co., of Howdon, near Newcastle, is shown in Fig. 136. It consists of an oblong cast-iron tank or well *a*, about 2 ft. 6 in. wide, 2 ft. from front to back, and 6 in. to 1 ft. deep, capable of containing 12 cwt. to 2 tons of lead, with which it is filled to the brim, the surface of the lead forming, in fact, the floor of the hearth. The floor thus formed is enclosed at the sides with blocks of cast iron, and another block of cast iron is placed behind, and is perforated for the passage of the twyer *b*, which conducts the blast into the furnace about 2 in. above the surface of the lead in the well. A brickwork shaft *c* proceeds upwards from the hearth to the flue, and behind it is blind flue or pit *d*, into which the "hearth ends" (dusty matter which comes off with the "fume") may fall, and from which it is removed as convenient by the door *e*. The front opening to the hearth is sometimes provided with a sliding shutter *f*, which, by means of a counterpoise, can be raised or lowered in its grooves so as nearly to close in the front of the hearth. Extending forwards from the front of the hearth, and inclining downwards at an angle from it, is an iron plate called the "fore-stone" or "work-stone," in which is a groove *h* leading towards an iron pot *i*, kept hot by a little fire *j* beneath. The ore is fed in either from the front or through a hopper *k* at the side. The chimney of the fire which keeps the lead pot hot is shown at *l*. The fuel used may be either peat or coal, the latter being general. A fire being made upon the hearth, and piled up chiefly behind, a moderate blast is put on, the ore (sometimes previously calcined) is thrown in, and the shutter (if there be one) is let down. After the lapse of a few minutes, the workman in-

troduces a poker and stirs up the fuel and ore, and from time to time repeats the process with fresh small quantities of ore, adding fuel as it appears requisite. At intervals of a few minutes, he raises the shutter, draws forward a portion of the charge on to the fore-stone, and picks out from it portions of "grey slag," which he pushes aside and ultimately throws off on the floor of the workshop at the side of the hearth. As the lead forms, it runs into the well,

FIG. 136.



and overflows along the channel of the fore-stone into the pot set to receive it, from which it is ladled into moulds. It is a process which requires constant manipulation of the charge, 2 workmen being continually occupied in adding ore or fuel, poking up the charge, &c., at intervals of a few minutes. Lime is used, as in the Flintshire process, to thicken the slags. (Dr. Ballard's Report.)

Reverberatory furnaces.—The employ-

ment of reverberatory furnaces for smelting galena depends upon the double decomposition of the lead sulphate obtained by the roasting and of the non-oxidized sulphur when these two react on each other. It can only be applied to ores containing 55 per cent. of lead and at most 4 to 5 per cent. of quartz or clay, otherwise there results a formation of lead silicate difficult to reduce. The presence of blende or pyrites produces oxysulphides which render the slag more fluid; this mechanically holds some grains of lead, whence the necessity for liquation as practised at some works. Gruner prefers to treat these rich residues in a shaft furnace, and to avoid the liquation. The rapidity of the reverberatory method differs much in different localities: it is slow and gradual in Carinthia, more rapid in Brittany, and much quicker still in British, Spanish, and Belgian works.

In Carinthia, the process is as follows: A charge is made of an ore containing a little blende and pyrites, as gangue, to a depth of about 2 in. on the inclined floor of the furnace; the roasting is conducted slowly for 5 hours, followed by stirring up for another 4 or 5 hours. By reason of the moderate heat of the roasting, the lead sulphide is only partially reduced; in the presence of the lead sulphate formed, a certain quantity of lead oxide remains in the bath, and sulphuric acid is disengaged. At the moment of stirring, the temperature rises; there is then complete reduction and decomposition of the lead oxide, with formation of metallic lead, a result which may be expressed by the following equations:

$$2\ PbS + 2\ PbO\ .\ SO_3 + 3O = Pb_2S + 2\ PbO + 3\ SO_3$$

and $$PbS + 3\ PbO = 4\ Pb + 3\ SO_3.$$

This last equation points to the proportions of oxide and sulphide desirable to maintain after the first period. There remains on the bed, after the reaction which follows the stirring, an appreciable proportion of rich cinders, containing about 40 per cent.; these are set apart for ultimate treatment by liquation. In Carinthia, the heating is done with wood; in some experiments in Belgium with this furnace and with a view to avoid the extreme slowness which characterises the Carinthian method, coal was employed; in this case, the air necessary for oxidation, instead of passing through the grate, is admitted by holes immediately into the furnace.

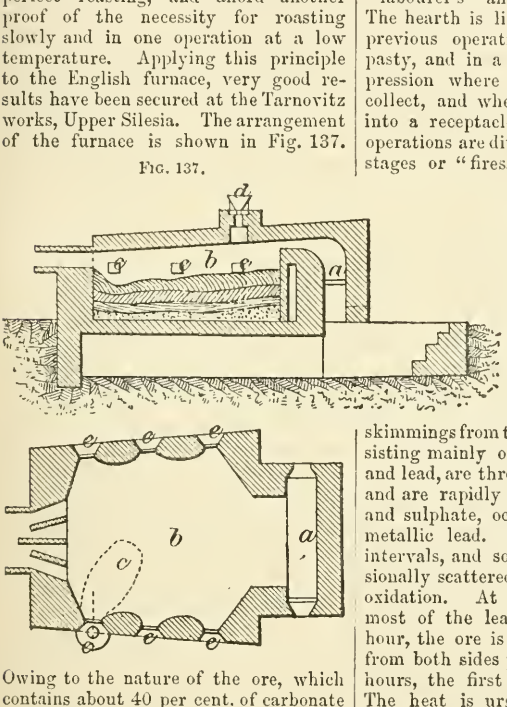
The Breton process being no longer in use, since the closing of the Albertville and Poullaouen works, it requires no description. Suffice it to say that it differs from the preceding in the roasting being performed more rapidly and at a higher temperature, resulting in a smaller yield and a less pure product. At Albertville, use was made of a furnace with a double hearth, one half for the roasting and the other for the reaction; this principle was also tried in Carinthia, because it gives a certain economy of fuel. An attempt was made to superpose the second hearth, but this was not successful.

The English process, properly so called, employs furnaces with an internal basin furnished with 3 working doors on each face. The object is not to raise the temperature too high at first, so as to produce lead oxide, as in the Carinthian process, followed by gentle heat to obtain the metallic lead. There is thus a succession of distinct periods of roasting and reaction, and is finished by adding a little slaked lime to cement the mattes; there remain rich cinders, which are feebly liquated and treated in a blast furnace. The fault of the English method is a too rapid action; some lead is liberated before the roasting is finished, and consequently there is a premature softening of the mass, which impedes the subsequent roasting; this entails a loss of lead which more than compensates for the gain in economy and rapidity of working. (The English process deals with a ton in 7 hours, while the Carinthian method only treats a charge of 4 cwt. in 9 or 10 hours.)

The English method has long been applied on the Continent. In Belgium,

for instance, they use long furnaces provided with a fire at each end, and in which the operation is conducted as if there were 2 distinct furnaces joined together. They experience great waste of lead by the rapid heating and imperfect roasting, and afford another proof of the necessity for roasting slowly and in one operation at a low temperature. Applying this principle to the English furnace, very good results have been secured at the Tarnovitz works, Upper Silesia. The arrangement of the furnace is shown in Fig. 137.

FIG. 137.



Owing to the nature of the ore, which contains about 40 per cent. of carbonate and sulphate of lead, the first roasting period is somewhat reduced, but is nevertheless much more gradual and prolonged than in England; it is indeed pushed to that point at which the correct proportions of sulphide and oxide are obtained for the final reaction. In the figure, *a* is the fire; *b*, the bed of the furnace; *c*, the well; *d*, hopper; *e*, working doors.

Prof. Huntington describes the English furnace as having a hearth about 8 ft. by 6 ft., separated from the fire by a bridge rising to within 18 in. of the arch, the latter gradually descending towards the chimney till it is only 6 in. above the hearth. The coaling door and ashpit are on opposite sides of the fireplace, known respectively as the "labourer's" and the "working" side. The hearth is lined with slags from a previous operation, spread while still pasty, and in a manner to leave a depression where the molten lead can collect, and whence it may be tapped into a receptacle placed outside. The operations are divided into 4 consecutive stages or "fires." (1) After lead has been tapped, and while the furnace is still glowing, about a ton of fresh ore is charged in through the hopper, a little coal being meantime put on the fire to maintain a moderate heat without sufficing to fuse the galena. After considerable roasting, the skimmings from the outer receptacle, consisting mainly of a mixture of sulphur and lead, are thrown in upon the charge, and are rapidly attacked by the oxide and sulphate, occasioning separation of metallic lead. The charge is stirred at intervals, and some small coal is occasionally scattered on it to regulate the oxidation. At the end of one hour, most of the lead is run off; after $1\frac{1}{2}$ hour, the ore is thoroughly stirred up from both sides; and at the end of 2 hours, the first fire is complete. (2) The heat is urged to bright redness, when the sulphide present reacts on the oxide and sulphate, and liberates much of the metal; the working and calcining endure about 1 hour, a little quicklime being introduced to help stiffen the unreduced portion. (3) The fire is driven still more fiercely for about $\frac{3}{4}$ hour, when the slags are again spread, and more lime is thrown in, combining with any silica present, and diminishing the fusibility of the mass. (4) The fire is driven to the utmost for $\frac{3}{4}$ hour, when the lead is tapped out,

and the slags are dosed with lime to cause their partial solidification, when they are withdrawn. A little coal being thrown in to deoxidize any lead oxide remaining, the furnace is ready for another charge. The whole operation lasts about 5 hours, and consumes about 12 cwt. of coal per ton of ore.

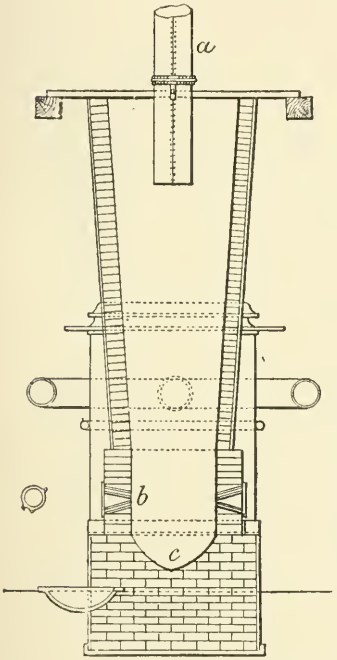
Dr. Ballard describes the use of the reverberatory furnace under two distinct headings—the Flintshire process and the Cornish process. The former is adopted in North and South Wales, Yorkshire, Shropshire, and Derbyshire. The latter is apparently peculiar to Par, Cornwall, and differs in some respects. It requires 2 reverberatory furnaces: the first, with a flat floor, is used for calcining the ore, which, after calcination, with addition of a little lime to prevent clotting in the early stage, is drawn out and introduced into the second or "flowing" furnace. This latter resembles the ordinary Flintshire furnace (Fig. 136), but the charge, mixed with culm (small anthracite), is introduced through doors opposite the tap-hole, instead of by a hopper in the roof. The charge is at once melted down with closed doors and strong heat. At a certain stage of the smelting, scrap-iron is introduced into the well of the furnace. The products, which are all run at one time from the tap-hole, are: first, lead; then a regulus or matte, consisting chiefly of iron protosulphide, but containing other metals, such as copper and silver, present in the ore; and lastly, a slag, which, since it is "clean" (*i.e.* contains only 1 to 1½ per cent. of lead), is thrown away. At some works, the first stage of the smelting, in which the greater part of the lead is got out, is performed by the Flintshire process, and the grey slag drawn out is then treated by the Cornish process. (Dr. Ballard's Report.)

Blast Furnaces.—A characteristic of working by fusion is the necessity of producing as far as possible only protosilicates, and not bisilicates, as in working by roasting and reaction. On roasting a quartzose ore, a great part of the lead is already in the state of silicate, and its precipitation will be more difficult according as the proportion of silica definitively combined is higher. As to the reduction, it is obtained by either iron or lime. The lime has a more energetic action, and the introduction of a ferrous flux renders the ashes more corrosive; but, on the other hand, slightly ferrous fluxes are more fusible, consequently the working can be done at a lower temperature, and the volatilization of lead is diminished. Finally, in treating blendic ores, the ferrous element combats the decomposition of the zinc silicates formed in the roasting, and as a consequence reduces the volatilization of this metal, which always carries away a certain amount of lead with it. In any case, very corrosive scoriæ are produced, necessitating energetic measures for preserving the twyers and sides. On this account it will be interesting to describe the successful plan adopted by Baron at the Pisa works. These treat quartzose and pyritous ores coming from the mines of Pallières, mixed with others from Sardinia. He commences by roasting in reverberatory furnaces, 25 to 40 ft. long and 6 ft. wide, with doors on one side only. This roasting is pushed to the point of cementing the matters, but not to fusion, which would render the ultimate reduction more difficult. For the fusion, after employing a Castilian furnace 6 ft. high and 3 ft. in diameter, blown by 2 or 3 twyers, Baron was led to increase the height of the furnace, and to close the throat by a charging door, as well as to replace the refractory bricks at the level of the twyers with cast-iron sides cooled by a current of water.

The only kind of high-blast furnace seen in use in England by Dr. Ballard is the Piltz furnace, shown in Fig. 138. It is adapted for highly argentiferous ores, and is much employed in the United States. It is charged through the top opening with ore, fuel, and an appropriate flux (iron in some form being essential), quite up to the top, into which an iron chimney *a* is introduced 3 or 4 ft., to catch any fume and conduct

it into the flues. The reduction of the metal takes place a little above the level of the twyers *b*, and the metal and slag, with a regulus or matte, collect in the well *c* below, whence they are run

Fig. 138.



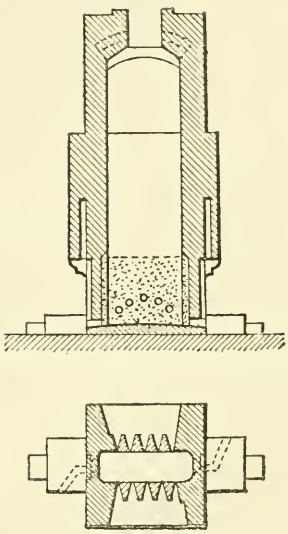
off. At the Sheffield Smelting Co.'s works, a form of blast furnace, in use for smelting rich argentiferous ores, is much lower than the Piltz, and is closed at the top, whence proceeds a flue for carrying off the "fume." A peculiar form of water-jacket is provided to prevent the destruction of the sides in the neighbourhood of the twyers. The jacket is made of cast iron, and has a number of inclined shelves, over which flows a stream of water. The water enters cold by a pipe at the top, and flows away nearly boiling by another pipe at the bottom, available for feeding a steam boiler. Omitting the water-jacket, a similar furnace is employed at Snailbeach for smelting slags. (Dr. Ballard's Report.)

Precipitation.—This method consists in precipitating the lead in a metallic state by another metal capable of taking its place in the chemical combinations. Iron complies with this requirement, and the operation is conducted in a blast furnace. The iron is added either in the form of scrap, more or less oxidized, or as cast-iron, or even as ore; but whatever the material which furnishes the iron as an element of precipitation, the process is costly, besides producing a certain quantity of cinders, which increases the loss of lead and silver. It is therefore only in special cases, for treating very quartzose, slightly argentiferous and cupriferous ores, or where fuel is scarce, that the precipitation method could be preferred to those of roasting and reaction, or roasting and reduction.

With a view to economy, the cheapest iron matters were long used; but this plan has been given up on account of the excessive corrosion caused, and the rapid destruction of the twyers. It was only in 1866 that attention was given to the employment of streams of cold water in the twyers or in contact with the sides. The experiment was made on a Raschette furnace, and succeeded perfectly. The Raschette furnace (Fig. 139) is used at Altenau, in the Harz. Its length is about 7 ft.; its breadth, which descends to 3 ft. at the level of the twyers, reaches 4 ft. 9 in. at the level of the throat; each face is provided with 5 twyers arranged in quincunx order. It is claimed that this system largely increases the production of metal, reduces the lead contents of the mattes, and permits the use of iron cinders instead of cast or scrap iron. This latter point once accomplished at Altenau, further experiments were made with other furnaces when provided with water twyers and tanks. At Clausthal, in particular, these efforts were crowned with success. The employment of a Raschette furnace with this object is

thus not an essential; but it is well to approach at least its bell-mouthed form, in order to reduce the losses by priming, and to obtain mattes and cinders poor in lead by reason of the complete reduction of the iron oxides.

FIG. 139.

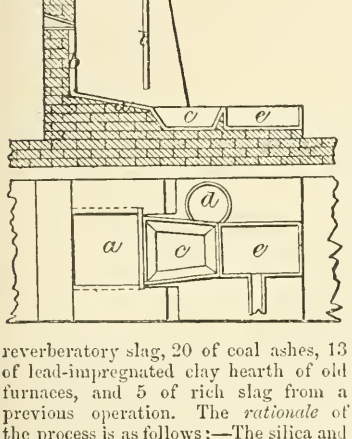


The use of ferruginous cinders has much reduced the cost of the precipitation process; nevertheless, the losses by slagging and volatilization have always remained high, and it is conceded that pure and rich ores should by preference be treated by roasting and reaction. If these ores are silicious, this latter method becomes inconvenient; but the precipitation method offers another difficulty—the necessity for subjecting the mattes obtained to long operations, whence result new losses of metal. Therefore in many works, the plan is adopted of having a preliminary roasting for silicious ores. Precipitation by ferruginous matters entails special difficulties if the ores are blendic; the zinc sulphide generally concentrates in the mattes, passing equally into the cinders, both which become very pasty; but at the contact of the lead cinders there is produced zinc silicate, and during this transformation a part of the zinc oxide formed is reduced by the fuel, giving metallic zinc, which vaporizes. By employing cast iron, the direct action of the iron on the zinc sulphide suffices to bring about the formation of metallic zinc. Finally, abundant vapours of zinc arise, of which a large proportion arrives at the mouth after having escaped a new oxidation, and carry away at the same time much lead and silver. There are hardly any but the slightly argentiferous copper ores which lend themselves well to the precipitation process. The copper remains in the state of sulphide in the mattes, where it concentrates, and these are subjected to a special treatment for the recovery of the copper; but it is still necessary that these mattes be not too abundant; that is to say, that the proportion of pyrites contained in the ore remains within certain limits, otherwise a preliminary roasting would still be required to eliminate part of the sulphur.

Slag Smelting.—In smelting the slags and cinders resulting from the foregoing operations, the object aimed at is the quantity of lead recovered without regard to its quantity; hence a very high temperature is adopted. The furnace employed, as will be seen from Fig. 140, bears a strong resemblance in general outline to the ore-hearth (Fig. 136, p. 337). Its dimensions are 36 in. high, and 26 by 22 in. in internal area. The bottom *a* is a cast-iron plate covered with 16 in. of closely packed porous cinders, which latter permit the molten lead to escape further oxidation while restraining the slag. The sides *b* are of sandstone. The molten metal escaping from *a* gains an outer reservoir *c*, which is cinder-lined in like manner, and thence runs into the iron melting-pot *d*, heated by a distinct fire. The accumulating slag flows off the cinder lining in *a* and *c*, and collects in a tank of water *e*, which causes it to break up so that the lead caught in it can be washed out. The fuel used is

peat, and a blast is introduced from the rear about 4 in. above the cinder bed. Coke is employed to urge the heat before charging in the slags. Prof. Huntington gives the ordinary charge as 100 parts

Fig. 140.



reverberatory slag, 20 of coal ashes, 13 of lead-impregnated clay hearth of old furnaces, and 5 of rich slag from a previous operation. The *rationale* of the process is as follows:—The silica and alumina of the clay and in the coal ashes combine with the lime and iron oxide in the reverberatory slag to form a very fusible slag; the lead is rendered metallic chiefly by the reducing action of the hot carbon on the lead oxide. In arranging the charge an effort is made to keep the coke in front and the slag at the back. In order to carry the draught up the middle of the charge, the twyer is allowed to form a prolongation of itself, termed a "nose," which it does by gathering molten slag on its end and chilling it to the solid state; this is only effected when the blast is at the right temperature, about 300° F. (149° C.), for if too hot no solidification will take place, and if too cold the nose will grow too long.

Another form of furnace is used for treating slags in and around Newcastle. It is variously known as the "economico," or Richardson's, and is a modification of the Castilian, being a blast furnace provided either with a blowing engine and 3 twyers, or a chimney and half-a-dozen draught-holes. The body is of firebrick, circular in form, $8\frac{1}{2}$ ft. high and $2\frac{1}{2}$ ft. in diameter; the bed is covered with tightly rammed clay and coke-dust, dished in the middle. The ore, previously roasted, and containing not over 30 per cent. of lead, is charged in at the top; the lead collects in depression, and is tapped out at intervals, while the slag runs over the side wall of the hearth into cast-iron trucks.

Condensing Vapours.—The fumes produced in the various metallurgical operations with lead contain in suspension extremely minute particles rich in lead, sometimes in such proportion as to amount to 7 per cent. of the total product of the works. Much of the solid material of the fume given off from the smelting-furnaces and slag-hearth collects in the flues of the works, and being very rich in lead, is from time to time taken out and smelted, but separately from the ores, since it contains metallic impurities such as zinc, arsenic, and antimony, which render the lead produced from it hard and unfit to mix with lead produced in the earlier processes.

French and Wilson, of the Sheffield Smelting Co.'s works, have studied the physical nature of lead-fume as it proceeds from the blast furnace used at these works. It consists of polished spheroidal particles, very uniform in size for the specimens taken at the same time, although those taken at different times frequently differed greatly. The smallest were about $\frac{1}{20000}$ in. in diameter. After passing along a flue for about 60 ft., these particles begin to aggregate into flakes, which become more numerous and larger as the distance from the furnace increases. Lead-fume appears to have no definite composition, as the proportion of its constituents varies in every specimen. French gives the following results of analysis of 2 specimens of fume proceeding from blast furnaces:—

	a.	*b.*
Lead oxide	44·80	68·35
Zinc oxide	4·80	1·80
Bismuth and copper oxides	1·52	..
Iron oxide	trace	..
Lead sulphide	..	2·25
Lime	..	2·63
Alumina	10·00	5·40
Arsenic and antimony oxides	3·03	..
Sulphuric anhydride (SO_3)	28·81	16·84
Insoluble silicious matter	9·00	2·25
	101·96	99·52

Lead-fume may also contain a little gold, and as much even as ½ to 1 per cent. of silver. When fluorine is present in the ores, or when fluor-spar is used as a flux, silicon fluoride will be present as a gaseous element in the fumes, but it will be decomposed by any watery vapour present, as it is in the flues of artificial manure-works.

Following is the composition of lead-fume collected in the flues of the Bagillt Lead Works, where reverberatory furnaces are used:—

	a.	*b.*
Lead protoxide	46·54	62·26
Lead sulphide	4·87	1·05
Iron and alumina sesquioxide	4·16	3·60
Zinc oxide	1·69	1·69
Lime	6·07	3·77
Sulphuric acid	26·51	25·78
Insoluble residue	10·12	1·97
(Dr. Percy)	99·87	99·43

The lead exists in the fume almost entirely as sulphate, so that the problem involved in its treatment for the recovery of the lead it contains is simply the reduction of that salt. Where the ore-hearth is in use, the material is merely wetted to make it agglutinate, and is then smelted much in the same way as the original ore. Where the reverberatory furnace is in use, it is smelted in this furnace. At Wass's Alderwasley Works, where poor ores and slags and various refuse matters are smelted down in a slag-hearth, more with the object of making fume (which is carefully collected) than to obtain lead directly, the smelting of the lead-fume collected and subsequently stored as a pasty mass, is conducted as follows:—It is charged on to the reverberatory furnace in the usual way, and heated or calcined for about an hour with occasional rabbling, until the whole has become melted and run down into the well. This part of the operation lasts about an hour. Fine slack is then added, and the whole is pushed back upon the floor of the furnace, and the heat is urged, when the lead separates and runs down into the well. The slag which forms is raked out by the doors opposite the tap-hole, and is added to the matters which are treated in the slag-hearth. The operation lasts 3½ hours and upwards. Care must be taken that solid fume does not pass off with the sulphurous gas into the air.

The essential element of condensation or collection of the fume is a very long flue, in the construction of which it is well to make provision for retardation of the current of gases through it in their way to the chimney. Such provision may be made by giving a large capacity to the flue, by giving it an angular or zig-zag course, by interpolating large chambers which are best placed at the far end of the flue, or zig-zags in its course, by introducing baulks or mid-feathers here and there, against which the current may impinge, or by hanging within the flue such things as iron hooping, bushes, old nets, &c., upon which the solid matters may be deposited. These various contrivances are adopted at different works. French says that invariably the fume is most abundant where the gases have suffered the greatest friction and fall in temperature. That this fact causes the fume to settle is also proved by the increased escape into the air for some time after the flues have been swept out. This has been proved by assays of the smoke, and is apparent at the top of the chimney to the eye. At many works some kind of arrangement for washing or damping the fume is adopted in addition. As to the value of this, however, opinions among lead-smelters differ very remarkably. Some of the largest smelters are satisfied that as good results are obtainable by dry flues as by the use of water in addition. A. O. Walker (who merely uses some steam produced by the evaporation

of water in his flue) says that the damp acid gases have injured his brick chimney-shaft, through which obviously some percolation has taken place. French goes further, and says that the use of steam in the flues is positively injurious to the deposition. He has carefully examined flues in order to determine this point, and has found less deposit in the parts where the steam has condensed into water than in the drier parts. The following particulars of the methods of condensation adopted at some works where that subject is most carefully attended to may be usefully given. The figures are to be regarded mostly as approximate:—

1. Smelt by reverberatory furnace. Aggregate length of flues (much of them underground), 2 miles; for the most part 7 ft. high by 6 ft. wide, but in some parts they are 10 or 12 ft. high. Early in their course the fume is made to pass through a number of shallow flues, at the bottom of which a layer of water is kept constantly supplied; the heated air converts some of this water into steam, which is carried forward with the fume. The greater part of the flue is disposed in the form of a helix, from the first part of which a branch or "relief-flue" passes away to a zig-zag of 20 rows or bendings, each of which being 14 yd. long (the length of the zig-zag), gives a total of 280 yd. of this arrangement. Old iron hooping is festooned upon iron rods within the flues of the zig-zag. The zig-zag terminates near the last coil of the helix. From the helix a straight flue conducts the fume up the side of the hill to the summit, where is a brick chimney-shaft 267 ft. high.

2. Smelt with ore-hearths. Formerly water condensation was used, but damage having resulted to the foundations of the works, it was abandoned, and dry condensation substituted. The flues are arranged in a block, and in the form of a zig-zag; 5 tiers of such zig-zags, one above another, having been built up, each tier consisting of 5 passages. The fume enters the nearest passage of the top tier, passes backwards or forwards along the 5 passages, and then drops down to the first passage of the tier below, and so on to the bottom. It then goes through a series of 4 chambers, from the last of which a straight flue conducts it up the side of a hill to the summit, where it terminates in a chimney 120 ft. high; the height of the hill is 110 ft. Following are particulars of the size of the flues and chambers, and the rate of passage of the fume through them:—

	Length. ft.	Width. ft. in.	Height. ft. in.	Capacity. cub. ft.
Flues . .	2610 ×	4	8 × 9 0 =	109,620
Do. . .	1530 ×	2	8 × 5 6 =	22,440
Do. . .	180 ×	4	8 × 5 0 =	4,200
Do. . .	360 ×	7	0 × 8 0 =	20,160
Chambers	43 ×	30	0 × 20 0 =	25,800
Do. .	27 ×	15	0 × 23 0 =	9,315
Do. .	24 ×	15	0 × 14 0 =	5,040
Do. .	20 ×	15	0 × 20 0 =	6,000
	4791			202,575

The volume of gases passing into the condensing-flues is 926 cub. ft. per minute; hence the length of time required for the gases to pass from the smelting-furnace to the exit at the main chimney is 3 hours 39 minutes. The condensation here is very effectual.

Cookson finds it more economical in the long run to roast the ore before smelting in the ore-hearth, notwithstanding that this process increases the cost of the smelting 34 per cent. Especially in the case of roasted ore, his exit-gases are remarkably free from (solid) fume, whereas in the case of raw ore the escaping fume is greater than that of the roasted ore, even taking into consideration the original quantities of fume made. Following are particulars of the results obtained on smelting 400 tons of ore, all the same assay, viz., 81 per cent., half of which was smelted raw, and half after having been roasted. These particulars are quite reliable, as extreme care was used:—

	200 tons, Roasted.	200 tons, Raw.
Lead, first fire . . .	73·10	60·80
Do. in grey slag , .	2·50	1·80
Do. in fume, hearth ends, top, &c .	5·40	18·40
	81·00%	81·00%

In the case of raw ore, the "hearth ends" were a large item, but very small and very much less in the case of the roasted ore. The proportion of fume (including "hearth ends") made is as 1, in the case of the roasted ore, to 3·28 in the case of the raw ore; but the testing of the exit-gases at the chimney showed that the fume escaping was as 1 in the case of the roasted ore to 3·35 in the case of the raw ore.

3. Smelt with the ore-hearth. The fume is passed through 3 large chambers, the first with 3 divisions and the others with 4, and the fume is made to pass through these chambers in succession on its way to a wooden chimney attached to the works, and 85 ft. high. The following is approximately the size of the chambers in feet, viz.:—

Height.		Length.		Width.		Cubical capacity.
40	×	46	×	15	=	27,600
65	×	33	×	27	=	57,915
18	×	54	×	54	=	52,488
						138,003

4. Smelt with the ore-hearth. There is in use here a "condenser" constructed of wood. There are 2 chambers side by side, with an interval of 3 or 4 ft. between, in which interval is a platform for the use of the workmen. The chambers are each about 84 ft. long by 4 ft. wide and about 12 ft. high, standing in what is virtually a trough of water, and each divided into 16 divisions by vertical partitions springing alternately from the roof and from beneath the surface of the water near the bottom of the chamber, the partitions springing from the top not reaching the surface of the water, those springing from below not reaching the roof, so that fume in passing through the chambers has to pass up one division and down the next in its course through the 16 divisions. At the top of each division is a colander, into which water is conducted by means of a wooden channel above, and from which the water falls as a shower upon some brushwood, with which all but the lower part of the several divisions is filled. Any solid matter washed out of the fume collects in the water-trough below. There is a provision for the water running off from the trough when it reaches a definite level. A fan is provided in the flue which conducts the fume to each chamber, and not only drives the fume through the chamber, but acts also beneficially in drawing off fume from the hoods beneath which the ore-hearths are erected in the smelting-house and from the calciners. The 2 fans were in use 24 years before requiring serious repair. From the condenser, a flue, with sloping sides, 5 ft. 8 in. high, 4 ft. wide at the spring of the arch, and 2 ft. wide at the bottom, conducts the fume to a wooden chimney $1\frac{1}{4}$ miles off. Wood, however, is an objectionable material for the condenser to be made of, since it allows of leakage.

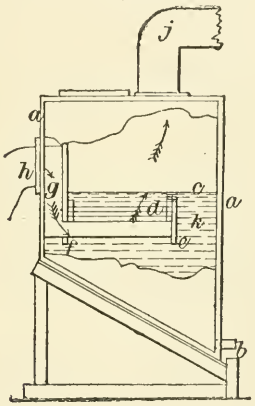
5. Smelt with the ore-hearth. Water condensation is used here, and is very effectual. An arrangement similar in many respects to (4) is adopted, but the condenser is erected in brickwork, which is better than wood. There is a pair of brick chambers about 20 ft. high, each divided by partitions into 6 divisions, over and under which alternately the fume has to pass. The water is supplied in gushes from a colander above each chamber through the agency of a tip-jack, and instead of bushes, rows of short drain-pipes are arranged on shelves within the condenser to break up the water as it falls through. From the washer the fume passes to 3 chambers of wood provided within with a zig-zag arrangement and brushwood, and from these, by means of a large flue, to a wooden chimney on the top of a hill; the length of the flue is 800 yd. The quantity of water used in this condenser is about 2 tons per minute. About half of the fume is taken out by the condenser, and the other half deposits in the long flue and zig-zags, through which the fume subsequently has to pass to the chimney. The sulphurous acid appears also to be in great measure washed out. The arrangement for the condensation is very effectual.

At many works water condensation is

little more than nominal, consisting of narrow showers of water passing here and there into the flues. It is sufficient to damp the fume with steam, but not to effect much more. French says that practical results accord well with the theory that rain-drops, with their comparatively enormous surface tension, are ill adapted to collect the extremely mobile particles of fume they encounter in their descent. It is also less easy to condense the fume proceeding from a reverberatory smelting furnace than from ore-hearths, since in the former case the efficiency of the smelting is dependent upon the strength of the chimney draught, while in the latter the draught need only be moderate, and the supply of air is given by a blower in just the moderate quantity requisite, and is strictly under control. But while the solid element of the fume can be arrested in the way described, long flues have no influence in arresting the escape of sulphurous acid from the chimney, and ordinary modes of washing with water fail to remove more than a moderate proportion of it. Probably such washing will remove more when the ore-hearth is used than when the reverberatory furnace is used, since in the former case the acid is less diluted with air. Hence it is important that the chimney in which the flue terminates should be removed to a good distance from habitations, and, if it be practicable, should be erected on the summit of some neighbouring hill.

A method of condensation devised by Wilson and French is in use at the Sheffield Smelting Co.'s Works. One great advantage it possesses is that it occupies little space. The principle of the condensation lies in this, namely, that the gases from the furnace carrying solid particles of fume with them are, after due cooling, forced through water in such a way that the water and fume are brought into very close contact and thoroughly mixed; the solid element is thus effectually wetted and retained in the water, and the soluble gases are, as far as the dissolving power of the water permits, dissolved. Fig. 141 represents the condensing apparatus as it stands. The condenser consists of a wooden box or case *a*, having a shelving bottom where the solid matter arrested collects, and a tap *b* at the lowest point, by which the contents of the condenser are from time to time run off. The case is filled with water to the level of *c*. The box is fitted at *d* with a series of 3 or 4 copper

Fig. 141.



wire-gauze screens, which are supported in a horizontal position between *f* and *e*; *f* is a partition reaching from the top to a depth of 3 ft. 6 in., and the whole width of the box, so as to form, with the wall of the case *a*, a broad channel *g*, into which the gases first enter from the pipe *h*. From the lower part of this channel, a horizontal series of triangular wooden tubes *i* pass forwards beneath the screens, and are provided at the top surface with perforations through which the gases pass out from them, and then through the screens (which are immersed in the water) and water, to be finally discharged by the pipe *j*, which leads to the chimney of the works. An open space *k*, formed by the side of the case and the plank *e* which supports the triangular pipes and the screens, acts as a return or overflow channel for the water which is set in motion by the ascending current of gases: this promotes the subsidence of fume to the

bottom of the box, and prevents at the same time a considerable amount of saltation of the water above the gauze, which would tend to wear it out.

The cooling arrangement in use at these works is as follows:—The smoke from the furnace passes by a wide inclined flue to the bottom of the first of a series of 4 upright tubes, through which it passes in succession from the top of the first to the top of the second, and from this to the bottom of the third, and so on. The cooling tubes are made of boiler-plates (being simply old boiler-tubes), and they are placed vertically, merely with the object of saving space and to facilitate cleaning, since all the fume which settles there is found in cavities prepared for its reception at the bottom of the supporting brickwork. From the cooler, the smoke passes through a wrought-iron pipe to a blower or fan which is worked by a direct-action engine, and which forces the smoke into and through the condenser.

With respect to the working results of the apparatus, French says that the quantity of lead, silver, &c., arrested amounts to 95 to 98 per cent. of that contained in the smoke as it leaves the furnace, and frequently even 95 to 98 per cent. of the metallic contents as they enter the condenser, without taking into account that which deposits in the flue leading from the furnace to the condenser. These results are obtained when the smoke is made to pass through a depth of 8½ in. of water and 3 wire-gauze screens. With greater depths of water and the same number of screens, as high percentages as 99 and 99·5 have been caught. With smaller depths, the results are lower, but still very satisfactory. The power required to work a condenser capable of condensing 95 to 98 per cent. is about 2 h.-p. for each ore-hearth or reverberatory furnace. Bell was commissioned by the Sheffield Smelting Co. to test the capabilities of the condenser and its adaptability to their work. He tested the smoke immediately before it entered the condenser (station 1), and as it left it (station 2), using the depth of water generally employed, viz., 7 in. above the perforations of the triangular pipes. He found that with this depth of water, 93 to 93¾ per cent. of the metallic lead was arrested; he took no account of the fume which was deposited in the flue between the furnace and the condenser, the quantity of which usually varies from ¼ to ⅓ of the total amount of fume which leaves the furnace. In order to condense the remaining 5 per cent. of fume (not arrested when 7 in. of water are used) a little extra depth of water (say 8½ in.), and therefore an extra blowing power, would be requisite; but this would add only about 1s. 6*d.* per 24 hours to the cost of working, and the extra cost would be in many cases repaid by the additional saving of fume. Bell also found that the condenser was effectual in arresting the sulphurous acid contained in the smoke. He says that a large proportion of the sulphurous acid gas was absorbed by the water in the condenser, and it was apparently not until this water was saturated that sulphurous acid began to make its appearance at the second station. When the water in the condenser has become saturated with this gas, an event which would rapidly happen in cases where the condenser was used in ordinary lead smelting, the escape of sulphurous acid by the exit flue would recur. French thinks that it might all be arrested by his condenser, if instead of charging it with a definite quantity of water, a constant stream of water were made to flow through it. But under this arrangement, settling-ponds for the fume suspended in the effluent water would have to be provided. Other modes of dealing with the sulphurous acid escaping after the saturation of the water in the condenser may be suggested. French thinks that the gas would be arrested if the smoke washed in the condenser were made to pass up a coke tower supplied with water at the top, and perhaps this might be effectual where the ore-hearth or any form of blast furnace is in use. But it may be doubted if a coke-scrubber

would arrest the acid when the smoke is so largely diluted with air as it is when proceeding from a reverberatory furnace. Still, the use of Wilson and French's condenser is calculated to facilitate subsequent disposal of the acid gases, and perhaps some chemical mode of dealing with them might be devised. French suggests that the waste gases might be propelled by means of a steam jet through a heating apparatus similar to the hot-blast heaters used in iron-smelting works, and the hot sulphurous acid, steam, and air passed through common salt, according to Hargreave's process. Other chemical agents calculated to arrest the sulphurous acid may be suggested, such, for instance, as a soluble sulphide (*e.g.*, the yellow liquor from alkali waste heaps, if available), or hydrated peroxide of iron. In the one case an alkaline hyposulphite, and in the other sulphate of iron would be produced, both of which have a commercial value. But it remains yet to be seen by actual working whether the condenser is equally applicable to the ordinary processes of lead smelting.

As respects vapours proceeding from smelting-houses where the ore-hearth is used, some advantage appears to be gained by the use of a sliding shutter, which can be let down in front of the opening to the hearth during part at least of the operation. At several works a hood is in use to catch the offensive fume proceeding from the slags when drawn forward upon the forestone, a pipe above conveying the fume to a chimney outside. With the same object, the ore-hearth is at some works set back within an arched recess capacious above and similarly communicating with the outside air. But even this is sometimes ineffacious. A suggestion made by Norman Cookson appears valuable, namely, to bring the hood well forward and to draw the air required for the blast from the upper part of the interior of it.

Where iron is used to remove sulphur, whether in the Cornish method of smelting or in smelting with the blast furnace, there is of course less sulphurous acid made, and therefore less to discharge into the air, than when iron is not used. The iron fixes the sulphur in forming a protosulphide. But unless the matte be thrown away, which would be a wasteful proceeding, there is still a liability of nuisance being created in the subsequent dealing with it. If the matte be burned or "calcined," sulphurous acid is again formed, and must be got rid of somehow, although it is more easy to utilize it without creating nuisance when it is formed in this way, inasmuch as it need not be inconveniently diluted with air, being capable of burning by itself without any fuel. (Dr. Ballard's Report.)

Wet Methods.—Wet methods have been tried for treating lead ores. They offer notable advantages with argentiferous ores, more especially those containing also an appreciable quantity of zinc. It is easy to see that the zinc increases the loss of lead in the dry method of treatment, either by rendering the slags pasty (when they mechanically retain minute grains of lead), or by augmenting the volume of metallic vapours carried out of the apparatus.

In the Roswag process, the ore, finely ground, and calcined if necessary, is treated with hydrochloric acid, more or less concentrated according to the ore, but usually consisting of a mixture of equal volumes of water and the commercial acid. After formation of the various chlorides, the mass is allowed to settle, and decanted hot. The cooling favours the deposition of the major part of the lead chloride; the liquor is again applied to more ore, and takes up a further quantity of lead chloride, which it deposits under similar conditions. The number of successive decantations required to exhaust the ore is generally 3 or 4.

The removal of the chlorides left in contact with the ore is effected by washing with hot water. The wash-waters and solutions are mixed, and concentrated if necessary. The remaining lead is precipitated by metallic zinc—old zinc from galvanization, for instance; as the amount of lead to be

precipitated is approximately known, the consumption of zinc as a precipitant is calculated at the rate of $\frac{1}{3}$ to $\frac{2}{3}$.

The metallic lead sponge, which contains the silver of the ore, is washed with a little water and pressed into bricks to remove the liquid which it holds; these bricks are put into a reverberatory furnace with an alkaline flux and a little charcoal to prevent oxidation.

The liquors containing the zinc chloride are heated to boiling; the zinc is precipitated by milk of lime, and the zinc oxide thus obtained is washed and compressed into bricks constituting a material assaying 55 per cent. and more of metallic zinc.

Maxwell-Lyte's process is for the separation of the metals lead, zinc, silver, copper, and iron, in mixed ores, by a wet chemical treatment, having in view the employment of the cheapest possible re-agents, such as brine, hydrochloric acid, old scrap zinc, hard spelter, chalk, and quicklime, thus rendering it possible to utilize economically on a large scale otherwise relatively valueless ores often hitherto treated as refuse, and to present them in marketable forms, either directly applicable in the arts, or treatable by the ordinary modes of smelting for the production of the pure metals. Following is a summary of the principal reactions on which it is based, taking for example a mixed ore containing blende with argentiferous galena and copper pyrites, such as the so-called bluestone of the Parry's Mountain and Mona mines of Anglesea, North Wales.

By calcining this ore, most of its sulphur is burned off, but part is oxidized into sulphuric acid, variable quantities of which remain combined with the metallic oxides produced. The gases resulting from this calcination, strongly charged with sulphurous acid, may be utilized for the manufacture of sulphuric acid. There generally remains in the calcined ores 3 to 5 per cent. of sulphur, in one form or another, but this does not interfere with the treatment of the ore.

When this calcined ore is finely pulverized and then treated for a certain length of time with hot or boiling hydrochloric acid of about 15 to 17 per cent. HCl in proper quantity, *i.e.* the quantity requisite to bring into solution the zinc and other more soluble bases, the zinc and the copper can be for the most part dissolved, and if this solution be now decanted off and cooled, most of the lead and silver remain insoluble, either with the gangue in the attacking-tub, or separate out of the decanted liquor as it cools. (For the most perfect working of the process, the acid should be used in such quantity as to leave an excess of about 5 or 6 per cent. of free HCl still in solution, together with the chlorides produced, but some latitude is allowable in this respect.) On adding another like quantity of hydrochloric acid, the lead, as well as that part of the silver which may have before escaped attack, becomes completely chloridized, and largely dissolved by this second acid, while more or less of the iron sesqui-oxide, always present in such ores after calcination, is taken into solution as sesqui-chloride. This iron sesqui-chloride seems materially to assist in completing the chlorination of the lead and silver. According, then, to the quantities of lead and silver present in the ore, the whole or part of these metals will have been dissolved by this second acid, but portions of these may, and generally do, remain mixed with the gangue as chlorides.

If again this solution of the lead and silver chlorides in hydrochloric acid, resulting from this second attack, be decanted into another vessel containing a fresh charge of calcined ore, it will take up more zinc and copper, and becoming partially neutralized, most of the lead and silver will again separate and fall down as the liquor cools, so that the clear liquid may be drawn off nearly free from these two metals.

These operations being completed, the first vessel where the ore was attacked, which for clearness may be called A, will contain a gangue together with more or less lead and silver chlorides, this gangue being still wet with some of

the acid liquor of the second attack containing iron sesqui-chloride. The ore, on the other hand, in the second attacking-vessel, called B, will have lost most of its zinc and copper, but will have got added to it some of the lead and silver drawn over from A by the second acid. By boiling the partially saturated acid with the fresh ore in the second vessel B, allowing it to settle, and decanting the liquor off, it is feasible, with the application of a fresh charge of acid, to chloridize all the lead and silver in the new batch of ore in B, and by decanting B once more on to a fresh charge of ore placed in A, nearly all the lead and silver this acid had taken up can again be precipitated on cooling, and so on *ad infinitum*, always obtaining as residues, on the one hand, the decanted (partially neutralized and cooled) liquors, rich in zinc or copper, but poor in lead or silver; and, on the other hand, gangues wet with acid, and containing the lead and silver completely chloridized. Were these liquors decanted off quite neutral, they would retain and carry over in actual solution but insignificant traces of lead or silver, and nearly the whole of these metals would remain with the gangue as chlorides when settled. In practice, however, where speed is desirable, it is not convenient to obtain them so, since they have to be decanted while still hot. Some traces of these metals are therefore still carried over in the hot decanted liquors, but these weakly acid zincous and cupreous liquors, when allowed to stand and cool, deposit nearly every trace of the lead and silver chlorides they may have carried over, whether in suspension or in actual solution.

The acid zinc liquor derived from the attacks of the several batches of ore by the hydrochloric acid, holds, besides zinc and copper chlorides, the chlorides of any other soluble bases the ore may have contained, usually iron, alumina, lime, and often some soluble silica. If this liquor be simply neutralized with chalk, *i.e.*, if chalk be added and stirred up with the liquor till a further addition ceases to cause effervescence, the iron and alumina present are for the most part precipitated, only that iron remaining in solution which the calcined ore may have afforded as protoxide or sulphide. If the liquor be now decanted through a filter, this precipitated iron, together with any excess of chalk which may have been added, as well as the silica and alumina present, are retained, while the liquor passes off containing the copper and the zinc. If the work has been carefully conducted, no more than 4 gr. of silver to each cub. ft. of zinc liquor should remain in solution, and even this silver, if it be considered worth while, may be collected by some spongy lead reduced by means of spelter from a solution of lead chloride in brine. The copper and these traces of silver may also be conveniently extracted by immersing bits of spelter or scrap zinc in the neutralized filtered solution; and finally, the zinc may be extracted as oxide by heating the solution to boiling, and treating it, *while boiling*, with the least possible excess of lime in the form of milk of lime.

The actual quantity of hydrochloric acid to be employed in the attack will of course depend in each case on the composition of the ore to be treated. In treating the Welsh bluestone already mentioned, about 6½ or 7 parts of acid, of 15 per cent. HCl, to 1 of calcined ore, may be used; but the quantity is easily adjustable for each kind of ore by an experiment in the laboratory on a small scale, or the quantity requisite may be calculated on an analysis of the ore. In practice it is found that even if double the amount of real HCl be employed which would be requisite for attacking and chloridizing the soluble bases (not including the iron the ore may contain), the solutions run off will not retain more than mere traces of lead or silver on cooling. Thus the zinc, and for the most part the copper, as chloride, may be separated and decanted off from the lead and silver chlorides which are left insoluble in the cooled liquors or with the gangue.

If now a quantity of strong brine (say

10 gal. of brine to every 4 lb. of lead the charge of ore may have contained) be next heated to boiling, and flushed hot on to the mixture of gangue with the lead and silver chlorides, and boiled, those lead and silver chlorides which separated from the zinc solution on cooling being returned to the gangue, the lead and silver are entirely taken into solution; and this brine being allowed to settle and run off as hot as possible into a clean vessel, and cooled, will deposit most of its lead as chloride, but *none* of its silver, this latter metal being retained entirely in solution, provided it be not present in larger proportion than about $\frac{1}{50}$ part of the lead, or providing there be at least about 10 gal. of brine to every 1·8 oz. of metallic silver the ore contained. Silver rarely occurs in larger quantity than this; but if it does, the quantity of brine must of course be increased and apportioned to it, so that all the silver may be taken up and retained in solution on cooling.

Lead chloride is soluble in boiling saturated solution of sodium chloride (brine) to the extent of about $53\frac{3}{4}$ parts (= 40 parts metallic lead) to 1000 parts by measure of boiling brine; whereas, on cooling down to ordinary temperatures, most of it crystallizes out until no more than about 10·8 of lead chloride (= 8 of metallic lead) to 1000 of brine remains in solution. Silver is soluble in the same liquid to the extent of about 1 of silver chloride (= 0·75 part of metallic silver) to 1000 of brine at about 50° to $53\frac{1}{2}$° F. (10° to 12° C.) and about 1·2 of silver chloride to 1000 of brine at about 77° to 79° F. (25° to 26° C.), and about double that quantity at a boiling temperature. The presence of lead chloride in the brine would appear not to diminish this rate of solubility of silver as chloride. The solution of silver chloride in brine appears to be peculiarly liable to that condition chemically termed super-saturation, so much so, that it will often be found that hot brine saturated with silver chloride will remain clear on cooling, until some determining cause, such as the addition of an atom of solid silver chloride, intervenes, when immediately the whole liquid will turn milky from the separation of silver chloride. It thus becomes evident that when lead and silver chlorides are present together, they are dissolved, and if care be taken to have brine enough present, all the silver is retained in solution on cooling, while most of the lead becomes deposited as lead chloride.

If the cooled brine, still containing, as it generally does, some ferric chloride, be now decanted from the precipitated lead chloride, and a strip of zinc be immersed in it, the lead chloride still remaining in solution and the whole of the silver chloride are reduced, together with formation of spongy lead and silver on the one hand, and zinc chloride which passes into solution on the other. It suffices, however, and is more convenient in practice, to only precipitate part of the lead from the brine, and by leaving this light spongy lead floating about, and agitating the brine with it, this lead gradually picks up all the silver from the brine, till it becomes very argentiferous. Successive charges of argentiferous brine may be run into a tub properly disposed for the purpose, with bits of spongy lead floating about, in it, and the silver be picked up from each such successive charge, the brine being thus desilverized. This brine, as it now contains but a fraction of the lead it had taken from the ore, and no silver, may be pumped up, neutralized if necessary, reheated, and used afresh. Thus the same brine may be employed over and over again to take more lead and silver out of successive charges of ore, depositing lead chloride in one tub, and all the silver with but a little lead in a third, while, by mere reheating, the same lot of brine becomes repeatedly regenerated in its solvent powers.

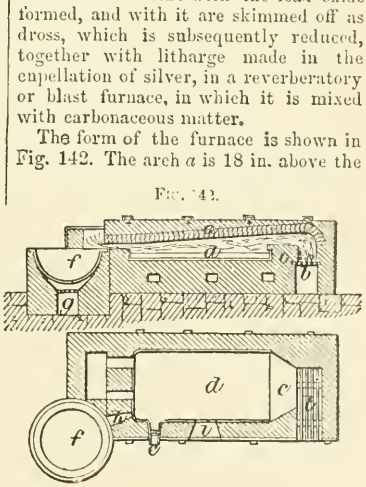
The above-mentioned employment of spongy lead is by far the most suitable and convenient in these circumstances, and offers special facilities for the subsequent separation and refining of the silver, being for this reason superior to iron, copper, or any of the metals whose employment has been previously

proposed as a means of collecting silver from its solutions. The fact of the silver remaining in the brine together with what lead is still retained in solution after cooling, especially facilitates this mode of its recovery, while it admits of the utilization of the same brine over and over again as a carrier and depositor of the lead on the one hand, and of silver on the other; and, as shown already, by so proportioning the quantity of the brine as to make it sufficient to retain the whole of the silver in solution, this metal can be entirely carried over into a separate vessel, where it may be thrown down completely, the brine being thus freed from silver at each successive operation. The process of desilverizing usually employed—or rather, what should be termed concentrating the silver in lead previous to cupellation—may be dispensed with when this process is employed, for the silver is thus at once obtainable with lead in a sufficiently concentrated form for immediate cupellation. Heating the brine during the desilverizing materially accelerates the operation, a tubful being thus able to be completely desilverized in a few hours. As the brine often contains traces of copper gathered from the ore, it is usually convenient to so apportion the lead thrown down as to have enough of that metal present to ensure proper cupellation, and further, in order to avoid loss, it is well not to obtain the silver in too concentrated a form. Lead with 2 to 4 per cent. of silver will be rich enough; the quantity of lead precipitated being of course proportionate to the time of immersion of the spelter, the quantity of the spelter employed, and the temperature of the brine. Argentiferous precipitates are easily, however, obtainable with 28 or 30 per cent. of silver from ores containing but a few oz. of silver per ton. Instead of spelter, zinc-dust may be used for this precipitation; or, instead of employing spongy lead at all for the collection of the silver, the same end may be obtained by stirring into the argentiferous brine some precipitated lead or copper sulphide. This will also gather the silver from the brine, though not perhaps quite so efficaciously or so rapidly as the spongy lead. This process is now being worked on a grand scale in Lancashire.

Softening Lead.—Crude metallic lead is always more or less "hard," that quality being mainly dependent upon the proportion of antimony, and to a less extent upon that of the other foreign metals which it contains. These may occur in the following extreme proportions: antimony, ½ to 3¾ per cent.; copper, ⅛ to ½ per cent.; iron, ⅛ to ¼ per cent.; silver, in almost any proportion. When the last-named metal is largely present, a particular process termed "desilverization" is employed; but in ordinary cases, the softening is accomplished by exposing the metal in a reverberatory furnace with a cast-iron bed to the action of dull-red heat with free access of air. This oxidizes the foreign metals, some of whose oxides pass off as fume, and the remainder combine with the lead oxide formed, and with it are skimmed off as dross, which is subsequently reduced, together with litharge made in the cupellation of silver, in a reverberatory or blast furnace, in which it is mixed with carbonaceous matter.

The form of the furnace is shown in Fig. 142. The arch *a* is 18 in. above the

FIG. 142.



hearth at the fire end and only 6 in. at the chimney end. The fireplace *b* measures 5 ft. long by 1½ ft. wide; the bridge *c* is 27 in. wide and 16 in. high. The hearth is occupied by a loosely

fitting cast-iron pan *d*, 10 ft. long, 5 ft. wide, and shelving from 9 in. deep at the chimney end to 8 in. near the fire; it has an outlet at *e*, closable by an iron plug. The lead is first melted in an adjacent iron pot *f*, heated by a separate fire *g*, in quantities of 8 to 10 tons at a time; when fluid, it is ladled into the gutter *h*, communicating with the softening pan. The softening process may be completed in a single day, or it may require several weeks, according to the amount of oxidation necessary to be accomplished. Its progress is noted by stirring up the metal through the working door *i* till an iridescent film makes its appearance; also by watching for a peculiar crystalline look in samples ladled into ingot moulds at intervals. The dross formed on the surface, consisting mainly of antimony and lead oxides, is occasionally raked off, mixed finally with coal, and pulverized in an edge-runner mill, ready for smelting in a small reverberatory. The resulting lead-antimony alloy is reheated with new charges till it is fit only for typefounding.

A much simpler softening process, adapted for small quantities, is to throw repeated doses of a mixture of soda nitrate, soda, and lime upon the skimmed surface of the metal melted in a cast-iron pan, removing the dross as formed.

Desilverizing Lead.—Three methods are in use in this country, viz., Pattinson's, Parkes', and the Rozan method. By Pattinson's process the lead is melted in a series of 8 to 12 strong hemispherical cast-iron pots set in a row; the pots are of such a size as to be capable of dealing with 6 to 10 tons of lead, the last pot (the "market pot") being, however, smaller than the others; each is heated by a separate fire beneath. The lead melted in one of these pots is allowed to cool, and as it cools, lead, in great measure free from silver, crystallizes, and is removed by means of an iron ladle perforated with holes, through which the liquid lead strains away. The lead which remains liquid contains most of the silver. To enrich the liquid lead further, the operation is repeated in another pot, and the process is repeated until a rich lead is obtained, containing, say, 500 to 600 oz. of silver to the ton. The crystals of lead strained from the pots have also to be desilverized in a similar way. The rich silver-lead is then cupelled in a hearth made of bone-earth, where part of the lead is blown off and collected as litharge (to be subsequently reduced with carbonaceous matter in another furnace), while part is absorbed by the substance of the cupel. The ladle measures about 18 in. wide and 5 in. deep, with holes $\frac{1}{2}$ in. diam. and $\frac{3}{4}$ in. apart, and is fixed to a handle about 10 ft. long, half the length being of iron and half of wood. The lead operated upon is generally in "salmons" of 120 to 140 lb. Should it contain, say, 25 oz. silver to the ton, it may be filled into the middle pot of the series. It will then be melted; and when the whole is thoroughly liquid, the fire will be drawn, and the lead allowed to cool. As it cools, a workman keeps stirring the lead, and "slicing," or freeing from the sides, the portions setting on them. As the cooling proceeds, crystals begin to form; and when a sufficient quantity appears, a second workman withdraws the crystals from this pot by means of the perforated iron ladle, and passes them into the pot on his right, continuing to do so until he has thus moved $\frac{2}{3}$ of the lead. When he has done this, he withdraws with a solid-bottomed ladle the $\frac{1}{3}$ of liquid lead remaining, and moves it to the pot on his left. The central pot is again filled with original silver-lead, and the same operation is repeated. If this has been properly conducted, it will be found that the liquid lead removed to the left, instead of containing 25 oz. of silver per ton, as did the original lead, will now contain 50 oz. per ton; and the crystals moved toward the market pot will now only contain $12\frac{1}{2}$ oz. of silver per ton. It will readily be seen that, by repeating this operation successively in the various pots, the poor lead gradually becomes poorer, until it is so free from silver as no longer to pay for working; while the rich lead, on the other hand, will gradually increase in

richness till its silver contents make it fit for the refinery. In addition to the removal of the silver, another advantage is gained, in that the major portion of the antimony and copper go with the silver, while another portion is removed by oxidation during the heating.

The Rozan process, the invention of Luce Fils et Rozan, Marseilles, and known also as the "steam" process, is in theory very similar to the Pattinson process, but is applicable to lead which has not been previously softened, inasmuch as it effects the softening at the same time as the desilverization. The object sought is the enrichment of the lead by crystallization. One great advantage of the process (which indeed is mainly that which commends it to the lead smelter) is that it performs by mechanical agency, and so at comparatively small cost, what is performed less perfectly and at great cost by hand labour in the Pattinson process. Lead being melted and skimmed in a hemispherical pot, is run off into a cylindrical pot or "kettle" of iron, where some water is run over the top, and where steam is blown in below, causing great agitation during the cooling which then takes place. The lead crystallizes in the pot as the cooling proceeds, and the crust formed is broken down by hand from time to time. When the operation is believed to be completed, the enriched liquid lead is run out through a strainer by a tap-hole below into a pot sunk in the floor of the works. The kettle is provided with a conical cover furnished with doors, which can be opened for manipulating the contents, and a wide iron pipe proceeds from the summit of the cover to convey the steam and fume, which consist of lead and foreign metals, to a flue which leads to a series of capacious chambers in which the solid matter is deposited, and from which the final volatile matters pass away by another flue to the chimney of the works. The matter deposited in the chambers is smelted with litharge in a reverberatory furnace. The process is thus described by Norman Cookson, whose firm are working it on the Tyne.

Instead of using a row of pots, as in the old process, there are two only; of which the lower is placed at such a height that the bottom of it is 12 to 15 in. above the floor level, while the upper is placed at a sufficiently high level to enable the lead to be run out of it into the lower pot. The capacity of the lower pot, which in those most recently erected is 36 tons, should not be less than double that of the upper one. Round each pot is placed a platform, on which the workmen, of which there are two only to each apparatus, stand when skimming, slicing, and charging the pots. The upper pot is open at the top, but the lower one has a cover, with hinged doors; and from the top of the cover a funnel is carried to a set of condensers. At a convenient distance from the two pots is placed a steam or hydraulic crane, so arranged that it can plumb each pot, and also the large moulds, which are placed at either side of the lower pot.

The mode of working is as follows:—The silver-lead is charged into the upper pot by means of the crane. When melted, the dross is removed, and the lead is run into the lower or working pot, among the crystals remaining from a previous operation. When the whole charge is thoroughly melted, it is again drossed; and in order to keep the lead in a thoroughly uniform condition, and prevent it from setting solid on the top and the outside, a jet of steam is introduced from the pipe. To enable this steam to rise regularly in the working pot, a disc plate is placed above the nozzle, which acts as a baffle-plate; and uniform distribution of the steam is the result. To quicken the formation of crystals, and thus hasten the operation, small jets of water are allowed to play on the surface of the lead. This, it might be thought, would make the lead set hard on the surface; but the violent action of the steam acts in the most effectual manner in causing the regular formation of crystals. Owing to the ebullition caused by this action of the steam, small quantities of lead are forced up, and set on the upper

edges and cover of the pot. From time to time the valve controlling the thin streams of water playing on the top of the charge is closed, and the workman, opening the doors of the cover in rotation, breaks off this solidified lead, which falls among the rest of the charge, and instantly becomes uniformly mixed with it. Very little practice enables an ordinary workman to judge when $\frac{2}{3}$ of the contents of the big pot are in crystals, and $\frac{1}{3}$ liquid; and when he sees this to be the case, instead of ladling out the crystals ladleful by ladleful, as in the old Pattinson process, he taps out the liquid lead by means of 2 pipes, controlled by valves, the crystals being retained in the pot by means of perforated plates. The liquid lead is run into large cone-shaped moulds on either side of the pot; and a wrought-iron ring being cast into the blocks thus formed, they are readily lifted, when set by the crane. To give some idea of the rapidity of the process, it may be mentioned that, from the time the lead is melted and fit to work in the big pot, to the time that it is crystallized and ready for tapping, is in the case of a 36-ton pot from 35 to 45 minutes; and the time required for tapping the liquid lead into the larger moulds is about 8 minutes. Before the lead begins to crystallize, the upper pot is charged with lead of half the richness of that in the lower pot. Thus, when the liquid lead has been tapped out of the lower pot, it is replaced by a similar amount of lead of the same richness as the remaining crystals, by simply tapping the upper or melting pot, and allowing the contents to run among the crystals. The same operation is repeated from time to time, until the crystals are so poor in silver that they are fit to be melted, and run into pigs for market. The large blocks of partially-worked lead are placed by the crane in a semicircle round it, and pass successively through the subsequent operations.

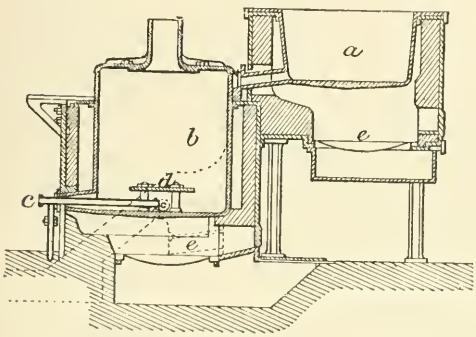
The process has other great advantages in addition to that of saving labour. In the first place, after taking into account the fuel used for supplying the crane power, and the steam for crystallizing, it still shows a great economy in fuel. In the case of Cookson's firm, they find that, as compared with the Pattinson process, as formerly carried out by them, they only use $\frac{1}{3}$ of the amount of coal, though of a slightly better quality. Another most important advantage is that the steam, in addition to its mechanical effect, produces an effect of a chemical nature. Almost all silver-leads, as received, contain impurities, such as copper, arsenic, iron, and antimony. In the Pattinson process, these extraneous metals had to be removed by calcination before the lead could be used in the separating department. But it is found that in the Rozan or steam process these extraneous metals, if they exist in moderate quantities (as is usually the case in English, Spanish, and other leads of similar quality), are readily oxidized by the steam; and that their presence in the desilverizing apparatus, instead of being a disadvantage, is a positive advantage, since, where a small quantity of antimony or copper exists, it has the effect of lessening the oxidation of the lead. A small quantity of lead and other oxides is carried mechanically from the lower pot by the steam and other gases, which escape from it after having done their work; but these are conducted by the funnel on the top of the pot cover to condensers, where the metals are practically all recovered. Those oxides are found to contain a very large quantity of antimony and copper, and in colour are nearly black, instead of the yellow proper to pure lead oxide.

To sum up, the advantages of the steam process, as compared with the old 6-ton Pattinson pots formerly used, are:—(1) saving of $\frac{2}{3}$ amount of fuel used; (2) saving of cost of calcination of the lead to the extent of at least $\frac{4}{5}$ of all that is used; (3) above all, saving in labour to the extent of $\frac{2}{3}$. The process has its disadvantages, and these are a larger original outlay for plant, and a constant expense in renewals and repairs. This is principally caused by

the breakage of pots; but with increased experience, this item has been very much reduced during the last 2 or 3 years.

The arrangement of the steam apparatus is shown in Fig. 143: *a* is a

Fig. 143.



melting-pot of 9 or 10 tons capacity, where the crude lead is melted; *b*, a pot of 15 tons capacity, where the lead is subjected to the action of the steam; *c*, pipe introducing the steam; *d*, cast-iron plate for distributing the steam through the mass; *e*, fireplaces.

Parkes' or the "zinc" process depends upon the affinity which zinc has for silver. The lead is melted in a Pattinson pot, and skimmed; then molten zinc is added to it, and stirred up with it; finally, the fire being damped, the metal is left to cool gradually. The zinc containing the silver now rises to the top, and is skimmed off with a perforated ladle; if necessary, the process is repeated, no more zinc, however, being used than is requisite to combine with the silver known to be present. The zinc is then distilled off the alloy in an appropriate retort, and condensed, when it can be used in subsequent operations. As worked in this country by Locke, Blackett & Co., the process is as follows:—A charge of silver-lead, usually about 15 tons, is heated to a point considerably above that which is used in either the Pattinson or the steam process. The quantity of zinc added is regulated by the amount of silver contained in the lead; but for lead containing 50 oz. to the ton, the quantity of zinc used is in most cases about $1\frac{1}{2}$ per cent. of the charge of lead. The lead being melted as described, a portion of this zinc, usually about $\frac{1}{2}$ the total quantity required for the charge, is added to the melted lead, and thoroughly mixed with it by continued stirring. The lead is now allowed to cool, when the zinc is seen gradually to rise to the top, having incorporated with it a large proportion of the silver. The setting-point of zinc being above that of lead, a zinc crust is gradually formed, and this is broken up and carefully lifted off into a small pot conveniently placed, care being taken to let as much lead drain off as possible. The fire is again applied strongly to the pot, and when the lead is sufficiently heated, a further quantity of zinc, about $\frac{1}{3}$ of the whole amount used, is added, when the same process of cooling and removing the zinc crust is repeated. This operation is gone through a third time, with the remaining portion ($\frac{1}{4}$ per cent.) of zinc; and if each of these operations has been carefully carried out, the lead will be found to be completely desilverized, and will only show a very small trace of zinc. In some works, this trace of zinc is allowed to remain in the market lead, but at Locke, Blackett & Co.'s works it is removed by subjecting the lead to a high heat in a calcining furnace. The zinc crusts, rich in silver, are freed as far as possible from the lead by allowing this to sweat out in the small pot, after which the crusts are placed in a covered crucible, where the zinc is distilled off, and a portion of it is recovered. The lead remaining, which is extremely rich in silver, is then taken to the refinery and treated in the usual manner. The quantity of zinc recovered

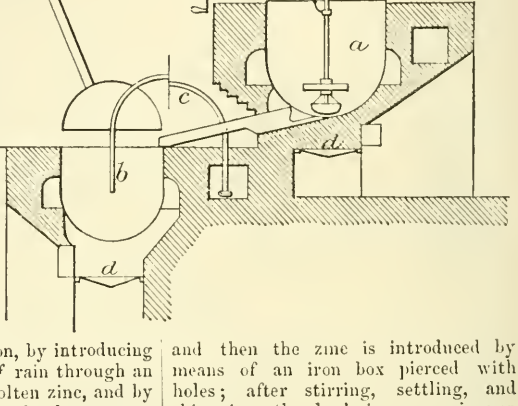
is as high as 50 to 60 per cent. of the total used.

This process has much to recommend it, in the low original cost of plant, the small amount of labour, and the extreme quickness with which the lead can be treated. The stock of working lead required is also small as compared with either the Pattinson or the steam process. Against this, however, is to be set the cost of the zinc which is lost.

The combination of the lead with the zinc is effected in several ways, *e.g.*, by mechanical agitation, by introducing the lead in a kind of rain through an iron sieve into the molten zinc, and by dispersing the zinc drop by drop among the molten lead by putting it (the zinc) into an iron colander, which is plunged into the lead.

Similarly, a plurality of methods have been proposed for separating the silver and zinc compound produced by the desilverization of the lead. At Pisa, distillation is adopted: after a portion of the lead has been liquated from the material, the latter is placed in a crucible and heated to redness; the zinc distils over, and the residue of silver-lead left is cupelled. At Friedrichshütte, near Tarnovitz, the silver-zinc scums are liquated only to such a point as will leave lead enough to ensure that the proportion of zinc does not exceed 12 per cent.; they are then distilled in zinc muffle furnaces with coke powder. In the works on the Rhine, chlorination is preferred; it consists in mixing, at a low-red heat, lead chloride with the zinc crusts, and the result is a zinc chloride which separates, and a silver-lead which is cupelled. At Rothschild's works, in Havre, oxidation by steam has given very satisfactory results. The apparatus used is shown in Fig. 144. The lead is first melted in the upper pot *a*,

FIG. 144.



and then the zinc is introduced by means of an iron box pierced with holes; after stirring, settling, and skimming, the lead-zinc mass is run into the lower pot *b*, into which a current of superheated steam is conducted by the pipe *c*; there is thus produced zinc oxide and a rich silver-lead. The latter is cupelled, while the zinc oxide is washed to remove grits, and then affords pure zinc oxide, which is sold as zinc-white, and an impure lead oxide, which is reduced in a reverberatory furnace, or treated with hydrochloric acid to dissolve the zinc and liberate the lead; *d*, the fireplaces.

Sheet-lead. — As lead is made into sheets by rolling, the first process to which the "softened" and desilverized pigs are subjected is melting and casting into cakes of suitable size. About 10 tons are commonly melted at one time, and the liquid metal is, on raising a valve in the melting-pot, allowed to escape directly into the iron mould, which receives about 4½ tons. Lifting-hooks are previously adjusted under the cake, so that, when solidified, it can be lifted out of the mould and carried by a crane on to the table of the rolling-mill. The size of the cake is usually

7 ft. 10 in. by 5 ft. After remaining in the mould some days to cool, it is lifted out, and the rough edges are trimmed round with an adze. It is then placed upon the rolling-mill table, in the direction of its least width—that is, so that the breadth of 7 ft. 10 in. shall be invariable, while the 5-ft. length is increased by the rolling.

The mill is a single cylinder of cast iron, 30 in. in diameter and nearly 9 ft. long. It is geared directly to the main driving-engine, and has the adjustments common to all rolls. The table is composed of small rollers arranged in 2 parallel lines. Between them is a rack, the teeth of which serve as fulcra for the insertion of levers, whereby the cake is pushed under the cylinder. The rolling once begun, the metal passes to and fro under the roll about 150 times, so that it is finally reduced to a sheet 30 ft. long and of the width above stated. It then weighs 30 lb. to the sq. ft. This sheet is cut into smaller pieces by vertical knives, which are actuated by a screw, so that they move across the table and between the cylinders on which the metal rests. The smaller sheets are now rolled into 18-ft. lengths, and vary in weight from $2\frac{1}{2}$ to 10 lb. per sq. ft. These constitute the usual sheet-lead stock—the variation being $\frac{1}{2}$ lb. to the ft. up to 5 lb., and 1 lb. per ft. thereafter. Their principal use is in chemical works for lining acid-proof receptacles, notably sulphuric-acid chambers and concentrating-pans, and also for the interior of tanks, cisterns, &c.

Cookson & Co. have introduced an improvement in sheet lead rolling, as follows:—When lead is required for sheet-making, instead of running out the "market" lead into the usual pigs of about 1 cwt. each, it is run into large blocks of $3\frac{1}{2}$ tons, and by so doing a very great saving both of time and labour is obtained. These $3\frac{1}{2}$-ton blocks are taken on a bogie to the mill-house, where the mill melting-pot is charged with them by means of a double-powered hydraulic crane, lifting, however, with the single power only. Three such blocks fill the pot, and, when melted, are tapped on to a large casting-plate, 8 ft. 4 in. by 7 ft. 6 in., and about 7 in. thick. This block, weighing $10\frac{1}{2}$ tons, is lifted on to the mill table by the same crane as fills the pot, but using the double power; and is moved along to the rolls in the usual manner by means of a rope working on a surging-head. The mill itself, as regards the rolls, is much the same as those of other firms; but instead of an engine with a heavy fly-wheel, always working in one direction, and connected to the rolls by double clutch and gearing, the work is done by a pair of horizontal reversing-engines, in connection with which there is a very simple and at the same time extremely effectual system of hydraulic reversing. In the usual method there is no necessity for full or delicate control of lead-mill engines; but with this system it is essential, and the hydraulic reversing-gear contributes largely to such control. This may be explained as follows:—In all other mills, when the lead-sheet, or the original block, has passed through the rolls, and before it can be sent back in the opposite direction, a man on either side of the mill must work it into the grip of the rolls with crowbars. In Cookson's system this labour is avoided, and the sheet or block is fed in automatically by means of subsidiary rolls, which are driven by power. When it is required to cut the block or sheet by the guillotine, or cross-cutting-knife, instead of the block being moved to the desired point by hand-labour, the subsidiary driven rolls work it up to the knife; and such perfect control does the engine, with its hydraulic reversing-gear, possess, that should the sheet overshoot the knife $\frac{1}{8}$ in., or even less, the engine would bring it back to this extent exactly. Another point, which is one of the greatest improvements in this mill, is its being furnished with circular knives, which can be set to any desired width, be put in or out of gear at will, and which are used for dressing-up the finished sheet in the longitudinal direction. This is a simple mechanical arrangement, but one which is found to

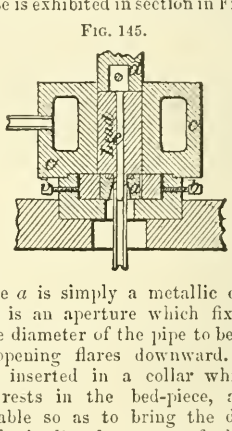
be of immense benefit, and which is far superior to the usual practice of marking off the sheet with the chalk-line, and then dressing off with hand-knives. The last length of the mill-table forms a weigh-bridge, and a hydraulic crane lifts the sheets from it either on to the warehouse floor, or to the tramway communicating with the shipping-quay.

Sheet-lead is also used in the manufacture of the so-called "tinfoil." A sheet of lead is placed between 2 of tin, and the whole is rolled and rerolled until the thin material with which all are familiar is produced. The tin serves in this case simply as a covering for the lead, and prevents the latter metal communicating its deleterious properties to substances enclosed in it.

The making of sheet-lead for lining tea-chests, &c., is an important industry of Hong-kong. It is made principally in the western districts. On entering one, workmen will be seen with shears cutting out the sheets of lead to the required sizes and shapes. The shears are simply large scissors firmly fixed to a solid block of wood some 2 ft. in height; the lower blade of the shears terminates in a square piece of iron instead of being pointed, as is the upper blade. The sheets of lead are of small size, and somewhat irregular in shape, and this arises from the method of manufacture. Beneath an iron pan, raised 12 in. or so above the ground, and carefully finished off, is a furnace, and at the side of the pan next the wall is the flue communicating with it. In this pan the lead is melted; when sufficiently hot, the workman takes 2 large square paving-tiles, and smoothly and carefully covers them with several layers of unsized paper. Having placed these tiles before him, one above the other, the workman raises the upper one with his left hand, and, taking a ladle of the proper size in his right, dips it in the melted lead and then pours its contents on to the lower tile. He then drops the upper tile and quickly presses the lead out into the form of a sheet. The paper being a bad conductor of heat, prevents the lead from solidifying immediately it leaves the ladle, and as by long practice the workman always ladles out the same quantity of lead, the sheets made vary but little either in size or thickness.

Leaden Pipe.—Leaden pipe is made by forcing the partially congealed molten lead through dies, in which a core is inserted, by hydraulic pressure. The essential part of the apparatus for this purpose is exhibited in section in Fig. 145.

FIG. 145.



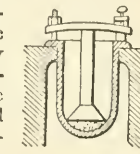
The die *a* is simply a metallic disc, in which is an aperture which fixes the outside diameter of the pipe to be made. This opening flares downward. The die is inserted in a collar which, in turn, rests in the bed-piece, and is adjustable so as to bring the die accurately in line by means of the set-screws *b*. Resting above die and bed-piece is the lead receptacle *c*. This is a heavy cylinder having an annular chamber formed in it to receive the steam by which it is kept hot. *d* is the press-plunger working downward, and in it is inserted the core *e*, which enters the die aperture. The metal is drawn off directly from the kettle, and the plunger is at once brought down upon it, so that it may be kept under moderate pressure until sufficiently congealed. The press is then set in operation, and the lead is forced through the annular space between the core and die, and emerges in the form of pipe. The process is quite rapid, and there is nothing further to do but reel-up the pipe as it is drawn. As soon as one charge is exhausted, or rather partially so, as a portion is left in the chamber, to which the new charge unites, more lead is

admitted from the furnace, and the operation is repeated. The amount of pipe made at a single pressure depends upon the weight of same when finished. Thus an extra-light 1-in. pipe weighs 2 lb. to the ft., and the chamber may, for example, hold 135 lb. Therefore $67\frac{1}{2}$ ft. of pipe are produced at each descent of the plunger. Different sizes of pipe are produced by substituting suitable dies and cores. The die is easily reached by lifting the chamber *c*, which is done by attaching the same to the press-plunger and elevating the latter.

Tin-lined leaden pipe is produced somewhat differently. Before the lead is run into the chamber, a mandrel is inserted, which closes the die aperture and extends up through the receptacle. This mandrel consists of a central stem, around which are grouped dovetailed sections, so that when the central portion is removed the sections are easily taken out, leaving a hollow space in the lead which is run in while the mandrel is in place. The sides of the mandrel are tapered, or rather crenelated, there being 3 or 4 shoulders and a different taper from each. The object of this is that after the mandrel is removed, the tin which is poured into its place may have several purchases against the lead which surrounds it. Of course before the tin is let in, the core, as already described, is inserted. Afterwards the pressure is applied in the usual manner, the result being that the pipe emerges with a thin lining of tin. Tin-lined leaden pipe and plain leaden pipe weigh the same.

Shot.—Shot, though sometimes made of lead alone, is almost always formed of an alloy of arsenic and lead, the arsenic being introduced in the form of arsenious acid or the sulphide (orpiment). The object of the addition of the arsenic is to slightly harden the lead, and render it capable of cooling to a globular form. Owing to the rapid decomposition of the arsenic, it is treated by itself in the bottom of the melting-kettle shown in Fig. 146. A cover is placed over the substance, and its stem, which rises up through the kettle, is fastened down. The lead is then added above the cover, and, when melted, the cover is lifted out of the liquid mass, which instantly becomes permeated by the arsenic beneath. The alloy thus produced contains 45 lb. of arsenic to the ton of lead, and is known as "temper." This again is added in the proportion of 1 per cent. to the pure lead, and thus the shot alloy, containing a very small percentage of arsenic, is produced. The making of quantities of the temper at a time is a great convenience, as the proportion of arsenic in the shot is thus kept uniform, while the melting can be done in the ordinary kettle in the summit of the shot-tower. The temper-pots hold about a ton of metal each, and the cooled product has a brownish gloss distinguishing it in a marked manner from the dull hue of the pure lead.

Fig. 146.



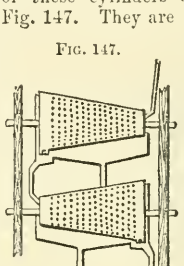
The manufacture of shot is almost universally conducted in tall brick towers with iron frames. In the top chamber is a melting-pot, whence the molten lead is dipped by workmen wearing thick gloves and wielding iron ladles. The metal is poured into colanders, which are simply perforated copper pans, resting in iron rings fastened over the well of the tower. In the bottom of the colander is placed a layer of the dross which rises to the surface of the lead during melting. This in a measure checks the too rapid escape of the melted metal, and is thought to have the effect of increasing the rotundity of the shot, possibly by expediting its cooling as it passes through. The holes in the colanders vary from $\frac{1}{50}$ to $\frac{1}{500}$ in., but the shot are of larger diameter than the orifices. In falling to the base of the tower, the particles of semi-fluid lead, acted upon alike over their whole surface by a current of air, are made to assume the globular form, and by the time they reach the bottom they are

sufficiently hardened by cooling to bear the shock of striking the surface of the water in the well below. The size of the shot is only approximately fixed by the sizes of the holes in the colanders. The mass is always larger than the hole from which it exudes, and as the period of dropping is not exactly uniform, perhaps half-a-dozen sizes are produced from the same sieve. Again, large-sized shot require to be dropped from a greater height than small-sized, and while in some cases 100 ft. is sufficient, in others an elevation of 150 ft. is hardly enough. Buckshot, as will be explained further on, are not made by the dropping process at all, owing to their size.

Various devices have been proposed for shot-making, having for their object the abolition of the tower. One process consists in pouring lead upon a revolving table on which is placed a cylinder of perforated sheet brass. The table is revolved with a velocity of 1000 ft. per minute on the periphery, and the lead is thrown through the perforations on the side, forming round shot, which strike against a linen screen placed to intercept them. A method has also been patented for dropping shot through short distances, but subjecting them meanwhile to a powerful air-current which cools them.

After the shot have reached the bottom of the well, they are at once lifted out by an elevator and thrown upon an inclined drying-table, over which they slide, falling ultimately into a wire-gauze rotating cylinder. Here they are rolled and ground together, and in this way the minute burrs upon them are removed. From the cylinder, another elevator lifts the shot upon a screening-table, which consists of a series of planes arranged at gradually decreasing heights. Between each 2 is an interval. The shot, being started at the end of the highest plane, will, if perfect, roll from one plane to another, jumping over the intermediate spaces; if imperfect, however, the latter become pitfalls, into which, sooner or later, it tumbles and is carried off into a receptacle, the contents of which go back to the melting-kettle. The good shot, after passing this ordeal, reach the separators. There are usually several tables, each devoted to a different size of shot and its approximating sizes. This is for convenience in future separating. The shot are next elevated to the top cylinder of a series, arranged on an incline. Two of these cylinders are represented in Fig. 147. They are conical in form, inclined, and covered with perforated sheet brass. Each cylinder serves as a sieve for a particular size of shot, retaining that and allowing all smaller sizes to escape. The shot, as the cylinder revolves, traverses its entire length, and then the small ones run out into the next cylinder below, and thus the sifting goes on until each cylinder has picked out the particular class of shot to which it is adapted.

Fig. 147.



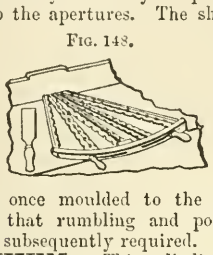
The sizes of shot are standard. The smallest is known as "dust," and then comes No. 12, which is 0·05 in. in diameter, 2326 shot going to the oz. The sizes then increase by hundredths of an inch up to $\frac{24}{100}$, of which there are 24 shot to the oz.

The shot being now assorted, polishing alone remains to be done. This is accomplished by placing the shot together with graphite (plumbago) in a box, which is rapidly rotated. This imparts the glossy black smoothness demanded by sportsmen. The shot are then weighed, bagged, and are ready for commerce.

Buckshot, which range in size from 22 to 38 hundredths of an inch, are moulded. The moulds represented in Fig. 148 consist of a series of pivoted bars, the outer pair of which have handles. The upper edges of these bars are hollowed to form the moulds, so that when they are closed together,

the opposite halves of each cavity unite, and it is only necessary to pour the lead into the apertures. The shot are

Fig. 148.



thus at once moulded to the proper size, so that rumbling and polishing only are subsequently required.

Lithium.—This alkali-metal occurs in appreciable quantity in several minerals, besides being very widely distributed through all 3 kingdoms (animal, vegetable, and mineral), in less perceptible proportions; it is present to the amount of 4 to 5½ per cent. in spodumene (an aluminium-sodium-lithium silicate), 1½ to 5¾ per cent. in lepidolite (lithia-mica), 2¾ to 3¾ per cent. in petalite (an aluminium-sodium-lithium silicate), and 1½ to 3¾ per cent. in triphyline (an iron-manganese-lithium phosphate). The best method of extracting lithium salts from lepidolite and petalite is Troost's, as follows:—A mixture of 10 parts finely-powdered lepidolite, 10 of barium carbonate, 5 of barium sulphate, and 3 of potassium sulphate, is fused at a very high temperature in a blast furnace; the heavy barium silicate and sulphate sink to the bottom, while the potassium and lithium sulphates form a layer at the top, and can be extracted by simple lixiviation; the sulphates are converted into chlorides by addition of barium chloride, the chlorides are evaporated to dryness, and the lithium chloride is extracted by treatment with a mixture of absolute alcohol and ether. The best method of extracting lithium salts from triphyline is Hugo Müller's. It consists in dissolving the ore in hydrochloric acid, oxidizing by nitric acid, precipitating the phosphoric acid by an iron persalt, evaporating to dryness, and extracting by hot water; manganese and lithium chlorides are thus dissolved; the manganese is precipitated by barium sulphide, and the excess of barium is removed by sulphuric acid; lithium oxalate is produced by evaporating with oxalic acid, and is converted into carbonate by ignition. The best method of preparing metallic lithium is Bunsen's, as follows:—Pure lithium chloride is fused in a thick porcelain crucible over a lamp, and decomposed by a current from a zinc-carbon battery of 4 to 6 cells, the positive pole being a small splinter of gas-coke, and the negative an iron wire about the stoutness of a knitting-needle; after a few seconds, the iron wire beneath the fused chloride is surrounded and coated with a silver-white regulus, which soon attains the size of a small pea; to obtain the metal, the wire and regulus are lifted out in an iron spatula, and the wire is withdrawn from the still molten metal, which is protected from ignition by the lithium chloride which coats it; after cooling under petroleum, the metal can be detached from the spatula by a penknife. Metallic lithium has a sp. gr. of only 0·5891 to 0·5983, and fuses at 356° F. (180° C.); it is softer than lead, can be made into wire, and welds at ordinary temperatures; it is much less oxidizable than sodium and potassium, and has a silvery lustre, but tarnishes on exposure; it attacks glass and porcelain below 392° F. (200° C.), and oxidizes on water without fusing; it is rapidly dissolved by dilute hydrochloric and sulphuric acids, slowly by concentrated sulphuric, and fuses and ignites in contact with nitric acid; it is more highly electro-negative than sodium, and burns with a white light when heated in the air, combustion taking place also on heating in bromine, chlorine, iodine, sulphur vapour, and anhydrous carbonic oxide.

Lubricants.—"Lubricants" are substances employed to reduce friction. "Friction" may be described as the effect produced by two bodies sliding one upon the other, which have upon their opposing surfaces minute asperities, that interlock each other. The sliding movement, which forcibly removes these minute irregularities, creates what we call friction. Friction

is reduced when these asperities are small, and lubrication is resorted to to prevent that loss of power caused by motion under these conditions. The chief lubricants used have a less co-efficient of friction than the parts in contact. The term "co-efficient of friction" is an expression which indicates the proportion which resistance to sliding bears to the force which presses the surfaces together. There is little friction when this amounts to only $\frac{1}{25}$; it is moderate when it is $\frac{1}{10}$, and it is very high when it is $\frac{1}{4}$, or 25 per cent., of the force which presses the surfaces together.

In a steam-engine, where many parts are moving, a large amount of friction is produced, which tends to stop those parts, and it would ultimately do it were they not continually re-supplied with fresh motion obtained by the burning of fuel. Hence it is apparent that the engine has not only to overcome the resistance of the work to be done, but also the resistance offered by its own parts. In other words, the amount of heat manifested in friction is the amount of extra heat that will have to be generated under the boiler, and the extra cost of working will be the cost of the fuel necessary to produce that heat. From the experiments of Morin, we find that the friction of a cast-iron shaft upon a dry bell-metal bearing amounts to ·2 of the transmitted power, while with a wrought-iron shaft the friction is more than ·25; therefore, if such shafts were dry and unlubricated, $\frac{1}{5}$ and $\frac{1}{4}$ respectively of the total fuel cost would be wasted in overcoming friction. By careful lubrication of the same shafts, the loss may be reduced to ·065 in the one case, and ·089 in the other. Hence the importance of a good lubricant. One of the next essential points is that it shall be properly distributed over the surface on which it is required, that just sufficient shall be used, and all waste avoided; otherwise, what would have to be spent in overcoming friction will have to be spent in buying oil.

For very heavy bearings, tallow and other solid lubricants are used, such as mixtures of sulphur and tallow, asbestos, soapstone with asbestos, graphite, caustic soda, beeswax, and other similar mixtures which find favour among locomotive engineers and those in charge of heavy machinery. The pressure that can be borne by a good lubricant for a useful length of time depends upon the nature of the bearings as well as upon the lubricant itself. The velocity of the rubbing action also must be taken into consideration. The maximum of pressure that solid lubricants will bear without destruction is unknown. For steel surfaces, lubricated with the best sperm-oil, moving slowly, 1200 lb. pressure per sq. in. of bearing surface has been found permissible. Under the pivots of swinging bridges, several thousand lb. per sq. in. have been found to work; for iron journals, 800 lb. per sq. in. should not be exceeded.

An efficient lubricant must exhibit the following characteristics:—(1) Sufficient "body" to keep the surfaces between which it is interposed from coming into contact; (2) the greatest fluidity consistent with (1); (3) a minimum co-efficient of friction; (4) a maximum capacity for receiving and distributing heat; (5) freedom from tendency to "gum" or oxidize; (6) absence of acid and other properties injurious to the materials in contact with it; (7) high vaporization- and decomposition-temperatures, and low solidification-temperature; (8) special adaptation to the conditions of use; (9) freedom from all foreign matters. The modern methods of testing the lubricating qualities of oils are directed to a discovery of the following points:—(1) Their identification and adulteration; (2) density; (3) viscosity; (4) "gumming"; (5) decomposition-, vaporization-, and ignition-temperatures; (6) acidity; (7) co-efficient of friction. The 1st and 2nd stages are described very fully in an original article by Dr. Muter in Spons' 'Encyclopædia,' pp. 1462–1477. The viscosity and gumming tendency may be simultaneously detected by noting the time required by a drop

to traverse a known distance on an inclined plane. A 9 days' trial gave the following result:—Common sperm-oil, 5 ft. 7 in. on the 9th day; olive-oil, 1 ft. 9½ in. on the 9th day; rape-oil, 1 ft. 7⅝ in. on the 8th day; best sperm-oil, 4 ft. 6½ in. on the 7th day; linseed-oil, 1 ft. 6¼ in. on the 7th day; lard-oil, 11⅝ in. on the 5th day. The day given is in each case that on which the oil ceased to travel. There are several ways of applying the plane test. A very simple and general test of fluidity is to dip blotting-paper in the oil, and hold it up to drain: symmetrical drops indicate good fluidity; a spreading tendency, viscosity. Retention of the oil on the paper for some hours at 200° F. (93½° C.), or for some days at ordinary temperatures, will show the rate of gumming. (Thurston.)

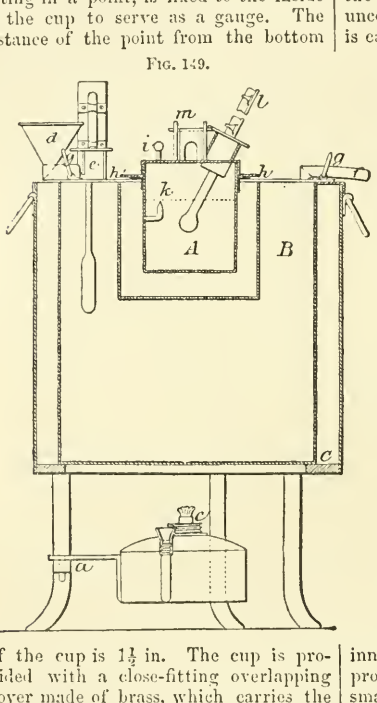
Putting aside the commoner characteristics of a good oil, such as the absence of acidity either natural or artificial, and the absence of gumminess, one of the most commonly believed ideas is, that an oil of high specific gravity is the best for lubricating purposes. Although this may be true in certain cases, yet from observations and experiments made over a long period it appears that they are not always the best, and that the point upon which we must rely is the viscosity. To test this, a French pourette graduated into 100 cc. is most useful. The pourette is fitted on a stand and filled with the oil to be tested; after allowing all bubbles of the air to separate, it is permitted to run through, and the time it takes to do so is carefully noted. At the close of the experiments, it will be found that the viscosities are directly proportional to the time taken; thus, if a mineral oil takes 15 seconds, and rapeseed-oil 45 seconds, the viscosity of rapeseed-oil is 3 times that of the mineral. The temperature may be either 60° or 90° F. (15½° or 32° C.), but the latter is preferable, as the oil may be subjected to that temperature when in use. Now, if an oil of very high viscosity, such as castor or rapeseed, were used to lubricate an engine of low horse-power, in all probability, instead of reducing the friction to a minimum, it would itself become a source of resistance, and increase the evil. Conversely, if an oil of very low viscosity were used to lubricate an engine of high horse-power, the friction would be but slightly if at all reduced. Hence, looking at extreme cases, there exists a marked connection between viscosity and horse-power, and to ensure perfect lubrication, the viscosity must gradually increase with the ponderousness of the machinery. It is stated by one authority that the best method for mixing oils with this object is to take a basis of American or Scotch mineral oil at 0·885 to 0·903 sp. gr., and add olive, lard, rapeseed or castor oil to work up the viscosity. Olive and lard oils, when mixed with mineral oils in proportions of 10, 20, 25, and so on up to 75 per cent., are about equal in value as lubricants of the lighter class of machinery. Rapeseed-oil in like proportions is valuable where the machinery is of a heavier kind, or where the lubricant has to be used throughout on works in which the machines vary much; but in such a case it is better to divide them into classes, and use a special oil for each class. Castor-oil, mixed with mineral oil in varying proportions, may be used in the case of the most ponderous machinery. Cold mixed oils are considered preferable to those mixed at a temperature over 100° F. (38° C.).

Fire-testing is specially applicable to mineral oils. There are several forms of tester, as Tagliabue's, Millspaugh's, Abel's, Saybolt's, Parrish's, Salleron-Urbain's, Sintenis', Bernstein's, and Bailey's. The apparatus consists essentially of a receptacle for the oil to be tested, a water-bath surrounding the receptacle, a lamp for heating the water-bath, a thermometer to indicate the temperatures, an outlet for the vapour generated from the oil, and a means of reaching the oil itself.

The form of tester recognised in this country under the Petroleum Act, 1879, is shown in Fig. 149. The oil-cup A consists of a cylindrical vessel of 2 in

diameter and $2\frac{2}{10}$ in. internal height, with an outward projecting rim *h*, $\frac{5}{10}$ in. wide, $\frac{3}{8}$ in. from the top, and $1\frac{7}{8}$ in. from the bottom of the cup. It is made of gun-metal or brass, tinned inside. A bracket *k*, consisting of a short stout piece of wire bent upwards and terminating in a point, is fixed to the inside of the cup to serve as a gauge. The distance of the point from the bottom

FIG. 149.



of the cup is $1\frac{1}{2}$ in. The cup is provided with a close-fitting overlapping cover made of brass, which carries the thermometer *l* and test-lamp *m*. The latter is suspended from two supports at the side by means of trunnions on which it oscillates, and is provided with a spout, whose mouth is $\frac{1}{16}$ in. in diameter. The socket to hold the thermometer is fixed at such an angle, and its length is so adjusted, that the bulb of the thermometer, when inserted to its full depth, shall be $1\frac{1}{2}$ in. below the centre of the lid.

The cover is provided with three square holes, one in the centre, $\frac{4}{10}$ in. by $\frac{4}{10}$ in., and two smaller ones, $\frac{3}{10}$ in. by $\frac{2}{10}$ in., close to the sides and opposite each other. These three holes may be closed and uncovered by means of a slide moving in grooves, and having perforations corresponding to those on the lid. In moving the slide so as to uncover the holes, the oscillating lamp is caught by a pin fixed in the slide, and tilted in such a way as to bring the end of the spout just below the surface of the lid. Upon the slide being pushed back so as to cover the holes, the lamp returns to its original position. On the cover, in front of and in line with the mouth of the lamp, is fixed a white bead *i*, the dimensions of which represent the size of the test-flame to be used.

The bath or heated vessel B consists of two flat-bottomed copper cylinders, an inner one of 3 in. diameter and $2\frac{1}{2}$ in. height, and an outer one of $5\frac{1}{2}$ in. diameter and $5\frac{3}{4}$ in. height; they are soldered to a circular copper plate C, perforated in the centre, which forms the top of the bath, in such a manner as to enclose the space between the two cylinders, but leaving access to the inner cylinder. The top of the bath projects both outwards and inwards about $\frac{3}{8}$ in.; that is, its diameter is about $\frac{6}{8}$ in. greater than that of the body of the bath, while the diameter of the circular opening in the centre is about the same amount less than that of the inner copper cylinder. To the inner projection of the top is fastened, by six small screws, a flat ring of ebonite, the screws being sunk below the surface of the ebonite, to avoid metallic contact between the bath and the oil-cup. The exact distance between the sides and the bottom of the bath and of the oil-lamp is $\frac{1}{2}$ in. A split socket similar to that on the cover of the oil-cup, but set at a right angle, allows a thermometer *e* to be inserted into the space between the two cylinders. The bath is further provided with a funnel *d*, and overflow pipe *f*, and two loop handles *g*.

The bath rests upon a cast-iron tripod stand, to the ring of which is attached a copper cylinder or jacket, flanged at the top, and of such dimensions that the bath, while firmly resting on the iron ring, just touches with its projecting top the inward-turned flange. The diameter of this outer jacket is 6½ in. One of the three legs of the stand serves as support for the spirit-lamp attached to it by means of a small swing-bracket *a*. The distance of the wick-holder *c* from the bottom of the bath is 1 in.

Two thermometers go with the apparatus, one for ascertaining the temperature of the bath, the other for determining the flashing-point. The former has a long bulb and a space at the top. Its range is from about 90° to 190° F. (32° to 88° C.). It is furnished with a metallic collar fitting the socket, and the part of the tube below the scale should have a length of about 3½ in., measured from the lower end of the scale to the end of the bulb. The thermometer for ascertaining the temperature of the oil is similarly fitted with collar and ivory scale; it has a round bulb, a space at the top, and ranges from about 55° to 150° F. (13° to 66° C.); it measures from end of ivory back to bulb 2¼ in.

The test is applied in the following manner:—The apparatus is placed where it is not exposed to draughts. The water-bath is filled by pouring water into the funnel *d* until it begins to flow out at the spout of the vessel. The temperature of the water at the commencement of the test is to be 130° F. (54½° C.), attained in the first instance either by mixing hot and cold water in the bath, or in a vessel from which the bath is filled, until the thermometer which is provided for testing the temperature of the water gives the proper indication; or by heating the water with the spirit-lamp (which is attached to the stand of the apparatus) until the required temperature is indicated.

When a test has been completed, this water-bath is again raised to 130° F. (54½° C.) by placing the lamp underneath, and is readily achieved while the petroleum-cup is being emptied, cooled, and refilled with a fresh sample to be tested. The lamp is then turned on its swivel from under the apparatus, and the next test is proceeded with.

The test-lamp is prepared for use by fitting it with a piece of flat plaited candle-wick, and filling it with colza- or rape-oil up to the lower edge of the opening of the wick-tube. The lamp is trimmed so that, when lighted, it gives a flame of about 0·15 in. diameter, and this size of flame, which is represented by the projecting white bead *i* on the cover of the oil-cup, is readily maintained by simple manipulation from time to time with a small wire trimmer.

When gas is available, it may be conveniently used in place of the little oil-lamp, and for this purpose a test-flame arrangement for use with gas may be substituted for the lamp.

The bath having been raised to the proper temperature, the oil to be tested is introduced into the petroleum-cup, being poured in slowly until the level of the liquid just reaches the point of the gauge which is fixed in the cup. In warm weather, the temperature of the room in which the samples to be tested have been kept should be observed in the first instance, and if it exceeds 65° F. (18° C.), the samples should be cooled down to about 60° F. (15½° C.), by immersing the bottles containing them in cold water, or by any other convenient method. The lid of the cup, with the slide closed, is then put on, and the cup is placed in the bath. The thermometer in the lid of the cup has been adjusted so as to have its bulb just immersed in the liquid, and its position is not under any circumstances to be altered. When the cup has been placed in the proper position, the scale of the thermometer faces the operator.

The test-lamp is then placed in position upon the lid of the cup, the lead-line or pendulum, which has been fixed in a convenient position in front of the operator, is set in motion, and the rise of the thermometer in the petroleum-cup is watched. When the temperature has reached about 66° F. (19° C.), the

operation of testing is to be commenced, the test-flame being applied once for every rise of one degree, in the following manner:—The slide is slowly drawn open while the pendulum performs three oscillations, and is closed during the fourth oscillation.

If it is desired to employ the test apparatus to determine the flashing-points of oils of very low volatility, the mode of proceeding is to be modified as follows:—The air chamber which surrounds the cup is filled with cold water to a depth of 1½ in., and the water-bath is filled as usual, but also with cold water. The lamp is then placed under the apparatus, and kept there during the entire operation. If a very heavy oil is being dealt with, the operation may be commenced with water previously heated to 120° F. (49° C.), instead of with cold water.

The schedule omits to state that the length of the pendulum to be used shall be 2 ft. from the point of suspension to the centre of gravity of the weight.

The "flashing-point" of an oil is understood to mean the temperature at which the escaping vapour will momentarily ignite; the "burning-point" is that at which the oil takes fire and burns. Lubricating oils should always flash above 250° F. (120° C.), and take fire at a considerably higher temperature. Animal and vegetable oils do not vaporize, but decompose at high temperatures, beyond the range of a water-bath. A comparison of petroleum, sperm-oil, and lard-oil showed the following respective figures:—Flashing-point: 245° F. (118° C.), 425° F. (219° C.), 475° F. (246° C.); igniting-point: 290° F. (143° C.), 485° F. (252° C.), 525° F. (274° C.); burning-point: 300° F. (149° C.), 500° F. (260° C.), 525° F. (274° C.). The standard animal and vegetable lubricating oils, and all mineral oils of good body and high sp. gr., decompose or vaporize only at temperatures exceeding that of steam in ordinary engines, the former usually and latter sometimes bearing steam at locomotive pressure. The precise value of any lubricating material is best ascertained by one of the many forms of apparatus devised for this purpose, such as McNaught's, Napier's, Ingham and Stapper's, Bailey's, Ashcroft's, Crossley's, Van Cleve's, Hodgson's, &c., fully described and figured in Thurston's work on Friction.

The suitability of a lubricating medium depends upon the character of the work being done, and is not constant. In order to procure the nearest possible approach to what is required for special purposes, many compounds are now in the market, being mainly mixtures of mineral and animal or vegetable oils in proportions calculated to develop the particular characteristics required. The general experience gained of various oils used for lubricating tends to the following results:—(1) A mineral oil flashing below 300° F. (149° C.) is unsafe, on account of causing fire; (2) a mineral oil evaporating more than 5 per cent. in 10 hours at 140° F. (60° C.) is inadmissible, as the evaporation creates a viscous residue, or leaves the bearing dry; (3) the most fluid oil that will remain in its place, fulfilling other conditions, is the best for all light bearings at high speeds; (4) the best oil is that which has the greatest adhesion to metallic surfaces, and the least cohesion in its own particles: in this respect, fine mineral oils are 1st, sperm-oil 2nd, neatsfoot-oil 3rd, lard-oil 4th; (5) consequently the finest mineral oils are best for light bearings and high velocities; (6) the best animal oil to give body to fine mineral oils is sperm-oil; (7) lard- and neatsfoot-oils may replace sperm-oil when greater tenacity is required; (8) the best mineral oil for cylinders is one having sp. gr. 0·893 at 60° F. (15½° C.), evaporating-point 550° F. (288° C.), and flashing-point 680° F. (360° C.); (9) the best mineral oil for heavy machinery has sp. gr. 0·880 at 60° F. (15½° C.), evaporating-point 443° F. (229° C.), and flashing-point 518° F. (269° C.); (10) the best mineral oil for light bearings and high velocities has sp. gr. 0·871 at 60° F. (15½° C.), evaporating-point 424° F. (218° C.), and flashing-point 505° F.

(262° C.); (11) mineral oils alone are not suited for the heaviest machinery, on account of want of body, and higher degree of inflammability; (12) well-purified animal oils are applicable to very heavy machinery; (13) olive-oil is foremost among vegetable oils, as it can be purified without the aid of mineral acids; (14) the other vegetable oils admissible, but far inferior, stated in their order of merit, are gingelly-, ground-nut-, colza-, and cottonseed- oils; (15) no oil is admissible which has been purified by means of mineral acids.

As the result of numerous experiments, Veitch Wilson is convinced that mineral oils are, if used alone, unsatisfactory lubricants; but bearing in mind the natural and almost ineradicable tendency of mineral oils to develop acid, and of vegetable oils by the absorption of oxygen to gum and clog the bearings and to induce spontaneous combustion, bearing also in mind the fact that mineral oils can now be obtained in every respect as safe as the finest animal oils, and that the admixture of mineral oil with animal or vegetable oil neutralizes the acidity in the one case and the acidity and oxidizing tendency in the other, he is of opinion that the safest, most efficient, and most economical lubricants for all manner of bearings are to be produced from a judicious mixture of animal or vegetable with good mineral oils. With regard to cylinder lubrication, the peculiar conditions are the liberation of natural acids from vegetable and animal fats and oils by the action of steam and heat, the action of these acids on the cylinders, and the evidence that as these acids are constituents of all animal and vegetable fats and oils, they cannot be removed by any process of refining. One of the lubricants largely in use is tallow, but there is conclusive evidence that it is the cause of considerable injury to the engine cylinders. From the mass of evidence he has been able to collect upon the subject, he is convinced that, if care was exercised in the selection of the oil, and equal care in its preparation and application, hydro-carbon oil would be found thoroughly efficient as a cylinder lubricant, absolutely harmless, and much more economical than tallow. The bulk of the cylinder oils now before the public are of American origin: they are usually sold pure, but sometimes a small percentage of animal or vegetable matter is added in order to increase their lubricating properties, and in his experience this has always been attended with most favourable results. The thickest oil that can be introduced to a cylinder is the best. Hot-air engines may be lubricated on precisely the same principles as steam cylinders, but gas engines present a new and special feature, as in their case the lubricant is not only subjected temporarily to the intense heat of the explosion, but also comes into direct contact with the flame, and is liable to be decomposed or carbonized thereby. If, therefore, animal or vegetable fats and oils are objectionable in steam cylinders, they are much more so in the cylinders of gas engines; and in the case of gas engines he would most emphatically protest against the use of any but pure hydro-carbon oils without any admixture. (*Colliery Guardian.*)

The results of W. H. Watson's experiments upon the corrosive action of various oils on copper and iron surfaces are worthy of reproduction here. After 10 days' exposure of copper to the action of the several oils named below, the effects were evidenced by the following quantities of copper held by them:— Linseed-oil, 0·3000 gr.; olive-oil, 0·2200 gr.; neatsfoot-oil, 0·1100 gr.; almond-oil, 0·1030 gr.; seal-oil, 0·0485 gr.; colza-oil, 0·0170 gr.; sperm-oil, 0·0030 gr.; paraffin, 0·0015 gr. Iron subjected to similar treatment for 24 days was affected to the following extent:— Neatsfoot-oil, 0·0875 gr.; colza-oil, 0·0800 gr.; sperm-oil, 0·0460 gr.; lard-oil, 0·0250 gr.; olive-oil, 0·0062 gr.; linseed-oil, 0·0050 gr.; seal-oil, 0·0050 gr.; castor-oil, 0·0048 gr.; paraffin, 0·0045 gr.; almond-oil, 0·0040 gr.; special lubricating-oil, 0·0018 gr. These results show that the extent of the action of any oil on one metal is no

guide to the degree in which it will affect another metal.

C. W. Volney has published the following results of an investigation of the effects of different oils upon brass. Strips of sheet brass were covered, each separately, with oil. The temperature was 81° F. (27° C.). The strips of metal were weighed; the temperature was kept uniformly at 81° F.; after 16 days, the metal was removed from the oil and carefully washed with alcohol, dried and weighed. (1) Menhaden-oil: weight of metal, 0·590. The oil had become thick, gummy, and covered with a tough skin. After cleaning and drying, the metal weighed 0·587; loss, 0·003. The metal itself was covered with a green film; the colour of the oil was unchanged. (2) Crude cottonseed-oil: weight of metal when immersed, 0·574. The oil had retained its original consistency. The metal was covered with a green film; the colour of the oil was unchanged. Weight of metal after washing and cleaning, 0·572; loss, 0·002. (3) Lard-oil: weight of metal when immersed, 0·572; the oil showed no change of consistency or colour; there was only a slight tinge of green on the metal, which weighed, after washing and cleaning, 0·5715; loss, not quite 0·001. (4) Olive-oil: weight of metal before immersion, 0·794. The oil was green from dissolved oleate; the metal was thickly covered with green film. Weight of metal after washing and cleaning, 0·790; loss, 0·004. (5) Neatsfoot-oil: weight of metal before immersion, 0·791; no change in colour or consistency of oil, but a green residue or precipitate had collected on the bottom of the glass; the metal was covered with green oleate. Weight of metal after washing and cleaning, 0·787; loss, 0·004. (6) Crude petroleum from Scio: weight of metal before immersion, 0·717. No change was observed in consistency or colour of the oil, and there was no change in the appearance or colour of the metal. Weight of metal after washing and cleaning, 0·717; loss, none. The foregoing trials express in themselves the fact that the mineral oils form the best protectors for brass. The figures obtained by expressing the loss caused by the oils upon the metal, give also the relative value of the oils in this respect. Reduced, the following table is obtained, which may be considered as an indicator of the dissolving or corroding effect of these oils upon brass:—

Menhaden-oil . . .	·511
Neatsfoot-oil . . .	·505
Olive-oil . .	·504
Crude cottonseed-oil . .	·348
Lard-oil . . .	·131
Crude petroleum from Scio .	·000

These figures may express the chemical effect of these oils upon brass, and thus give values for the estimation of these oils as protectors of metals; to form estimates of their values as lubricators, the above obtained factors will doubtless prove valuable, but the mechanical action in friction will have also to be considered. These figures also express merely results obtained with the oils under investigation, as the acidity of the vegetable and animal oils differ. Probably the results of their effects upon metals will differ; but in general it may be stated that these oils in course of time will invariably show acidity, and in this respect only mineral oils are excepted. (*Oil and Paint Rev.*)

The lubricating power of a mineral oil increases with its specific gravity. Wherever, therefore, in machinery there is great friction with heavy pressure, only *heavy* mineral oils should be employed, and if they are properly prepared—*i.e.* free from resins and acids—they retain their lubricating power at any temperature. Animal and vegetable oils, on the contrary, however pure, gradually lose this power, and, owing to the oxidizing action of the air, become thick, gummy, and eventually quite stiff, and hence continual oiling and frequent cleaning become necessary. The heavy mineral oils have not this tendency to become thick under the same influences. Then, again, at a low temperature, animal and vegetable oils become thick, or even solid, whereas mineral oil always remains liquid, and

even the greatest cold only makes it slightly thicker, but never solid. The chief advantage, however, of the mineral oils is that they do not act upon iron like those of animal and vegetable origin. As already stated, the latter are composed of fatty acids and glycerine, a combination which is broken up into its constituent parts by superheated steam. (On this fact the manufacture of stearine and glycerine depends.) The same decomposition, however, takes place, although only gradually, under the influence of atmospheric moisture even at the ordinary temperature. The free fatty acids attack the metals with which they are in contact, forming the so-called metallic soaps, and this takes place irrespective of the presence of steam. The affinity of the fatty acids for ferric oxide is indeed so great, that it seems as if the iron dissolved in them at the moment of contact. (*Leip. Färb. Zeit.*)

During experimental observations on paraffin-oils, it was found that certain oils burned somewhat imperfectly in different lamps, and an examination of these oils led to the discovery that they were contaminated so largely with lead compound as to lead to the choking up of the wicks, and ultimately to the lessening and practical extinguishment of the light. In the case of one of the oils, the wick of the lamp had to be changed several times during a single night, and the examination of these wicks proved that they contained so much lead compound as to leave, when charred, a fine network of metallic lead. The oil in question had been stored in a cistern or tank lined with sheet-lead, and notwithstanding the absence of affinity between paraffin-oil and other substances, as indeed its own name indicates, the oil had apparently acted upon the metal, and held the lead in solution. In order to determine how far paraffin-oil could act upon lead, a series of experiments was instituted, in which oils of various qualities, originally free from lead, were allowed to remain in contact with the metal for different periods of time. These experiments proved that all the samples of paraffin-oil which were experimented upon had more or less action upon metallic lead; that mere contact of the oil with the lead was sufficient to communicate traces of lead to the oil; and that in a week's time the oil invariably became so highly charged with lead that it was rendered unsuitable for combustion in ordinary lamps, owing to the encrusting of the wicks, and the consequent lowering of the luminosity of the flame. In order to render the experimental observations more complete, similar trials with paraffin-oil and other metals were carried on; and to enable the various experiments to be compared with each other, the same quality of oil was employed in the principal investigations with the different metals. Twelve series of experiments were made with the highest quality of burning-oil and the metals—lead was employed in 3 of the trials because this metal is more liable to be acted upon when the surface is bright than when the surface possesses the ordinary skin or coating of oxide and carbonate, and the results obtained with bright lead might not apply to tarnished lead. This difference in action is well known in the case of the chemical influence of different natural waters upon lead.

(1) Bright lead.—When paraffin-oil is brought into contact with scraped lead, where the surface is quite bright, the chemical action begins instantly, and a few moments are alone required to communicate the metal to the oil. In a day the action is so decided that the oil begins to present rather a cloudy appearance, owing to the presence of the lead compound; and on washing the oil with water, the latter when settled retains a milky appearance from the lead compound, which is apparently a basic salt, and has an alkaline action on test-papers. (2) Tarnished lead with unprotected edges.—Lead cut into small sheets and placed in the paraffin-oil, without any protection to the freshly cut edges, necessarily exposes a large surface of tarnished metal with the natural skin of oxycarbonate, and a

comparatively small surface of bright metal, where the fresh-cut edges are visible. The investigation showed that under these circumstances the lead is not so readily acted upon by the oil, but in a couple of days the oil gets impregnated with lead compound, and becomes unsuitable for illuminating purposes. (3) Tarnished lead with protected edges. —In this case the lead was taken with its natural skin, and the freshly cut edges were protected by wax. Under those circumstances, the paraffin-oil acts even less energetically, and though traces of the metal may be found in the oil in an hour from the commencement of the experiment, yet it takes about a week before the oil becomes largely impregnated with the metal. (4) Tin.— This metal is very slightly acted upon by the oil, and in a month's time the amount of metal dissolved in and diffused through the oil is very small, and is not sufficient to impede the combustion of the oil in lamps. (5) Copper.—A very slight action is apparent after a month's exposure, and practically the oil is not affected thereby as a luminant. (6) Iron is slightly affected by the paraffin-oil, and on 10 days' contact the oil becomes deeper in colour and throws down a fine ferruginous sediment. The oil itself is, however, not materially injured as an illuminating agent. (7) Zinc.—This metal is sensibly acted upon by the paraffin-oil, and the latter retains the zinc compound in solution and suspension. The oil is decidedly injured as a luminant. (8) Tin solder of the best quality, containing 2 parts tin and 1 of lead, is acted upon by the paraffin-oil, and the latter is injuriously affected as an illuminating agent. (9) Tin soldered with tin solder is also acted upon, and lead is dissolved out from the solder by the paraffin-oil. The quantity of metal dissolved out is not large, but is sufficient to influence the oil as a luminant. (10) Tinned copper is not practically affected by the paraffin-oil so far as the combustion of the oil is concerned, but traces of both the tin and the copper are found in the oil after a month's exposure. (11) Tinned iron is acted upon very slightly, but the oil does not suffer as an illuminating agent. (12) Galvanized iron is readily acted upon by the oil, and the quality of the oil for burning with wicks is sensibly injured.

These experimental observations demonstrate that the metals lead and zinc should not be employed in the construction of or in the lining of cisterns or other vessels intended for the storage or reception of paraffin-oils; that the metals tin, copper, and iron, as well as tinned copper and tinned iron, may be safely employed in the fabrication of the cisterns or other vessels; and that ordinary tin solder containing lead should not be used in the soldering of such cisterns or vessels. Galvanized iron should likewise be avoided. Whilst stating that the cisterns or vessels for the retention of paraffin-oil may be safely constructed of or be lined with tin, copper, or iron, it would be preferable to use cisterns or vessels lined with enamel in the interior, provided such could be obtained of sufficient size for the purpose. The ordinary enamelled iron pots present absolutely no surface upon which the paraffin-oil can act, and cisterns or vessels constructed in a similar way, with an interior lining of enamel, would retain the paraffin-oil for any time without affecting in the slightest degree the purity of the oil or its entire suitability for illuminating purposes. In cases where leaden cisterns or vessels have been in use for the retention of the paraffin-oil, there can be no doubt that the inferior illuminating power of the oil may be fairly attributed to the lead impregnation. The action is lessened much by washing over the surface of the lead with dilute sulphuric acid, which forms a coating of the insoluble lead sulphate, in or through which the paraffin-oil has comparatively a feeble action. The oil, however, does take up a little lead, and hence the impurity still continues to pass to the wick. A better protective coating is obtained by brushing over the surface of the lead with solution of sulphuretted hydrogen, and still better with ammonium sulphide, when a coat-

ing of insoluble lead sulphide is formed, on or through which the paraffin-oil has still less action than on or through the lead sulphate. The impregnation of the oil, however, still goes on, though in a minimum degree.

The paraffin-oil employed in the principal trials was of excellent quality, and was free from acid and alkali. The action, therefore, of the oil upon the metals was not due to the presence of any impurity in the oil. In other experiments made with different samples of paraffin-oils upon the metal lead, it was found that the power of action differed materially in the various oils, but such difference in degree of action was not traceable to impurities in the oils. It is probable, however, that the various proportions of the hydrocarbons present may have an influence in aiding or arresting the action of the oil upon the metal. (Dr. Stevenson Macadam.)

Some time since, Chevreul studied the effect produced upon the drying-oils by different metals. He found that under certain circumstances metals exerted an influence upon the oxidation of the oils; for example, linseed-oil, when spread upon a sheet of lead, dried immediately. Livache believed that the metals would act more energetically if in the fine state of division in which they are obtained by precipitation from solution, instead of using only surfaces of sheets of metal. He tried the effect of tin, copper, and lead on the oils, but only the last-named exerted any considerable action. The lead employed in the experiments was obtained by precipitation with strips of zinc from the solution of a lead salt; it was quickly washed with water, then with alcohol and ether, and finally dried *in vacuo*. If this lead is moistened with a certain quantity of oil, and then exposed to the air, in a short time an increase of weight is observed, and the more drying the oil the greater this increase. When raw linseed-oil is treated in this way, the increase of weight attained its maximum in 36 hours, while the same oil, if merely exposed to the air alone, requires several months to reach this state. A solid but elastic substance is formed, like boiled linseed-oil dried in the air. Experiments made with different oils show that the increase of weight is nearly the same as that of their fatty acids when exposed to the air for a few months:—

Oil treated with precipitated lead.	Increase of weight in oil in 2 days.	Increase of weight of fatty acid in 8 dys.	8 mos.
Linseed .	14·3 per cent.	..	11.0
Walnut .	7·9 „	..	6·0
Clove . .	6·8 „	..	3·7
Cottonseed	5·9 „	..	0·8
Beech-nut .	4·3 „	..	2·6
Rape . .	0·0 „	2·9	2·6
Sesame . .	0·0 „	2·4	2·0
Peanut . .	0·0 „	1·8	1·3
Rapeseed .	0·0 „	2·9	0·9
Olive . .	0·0 „	1·7	0·7

Cottonseed-oil was the only drying-oil that showed a marked exception; the fatty acid from it exhibited a very slight increase of weight. That is probably the reason why this oil can play a double rôle, as a drying and a non-drying oil, for it is used to adulterate linseed-oil on the one hand and olive-oil on the other. Contact with precipitated lead imparts to oil the property of absorbing oxygen rapidly. In his study of the oxidation of the oils, Cloez has shown that it is always attended with the total disappearance of the glycerine, and in Livache's experiments it was noticed that the glycerine was modified by the precipitated lead. If glycerine is mixed with precipitated lead in a tight bottle free from air, the lead soon vanishes, being oxidized at the expense of a portion of the glycerine, and then dissolved in it. These facts indicate that a rapidly drying oil can be obtained by simply treating linseed-oil for some time with red-lead or litharge, although the product thus obtained always remains greasy, and does not dry as well and quickly as boiled linseed-oil. In the arts, advantage may be taken of this action of lead toward drying-oils, as for example to prove the presence of cottonseed-oil in linseed-oil as well as in olive-oil. Probably boiling may be dispensed with by substituting mere contact of the oils

with precipitated lead, or solutions of lead and strips of zinc on which the lead may be deposited in a fine state of division. Oils prepared in this way are always of a lighter colour, and retain a greater degree of fluidity. Perhaps the bad smell of boiling-oils, and the great danger of their taking fire in the operation, can be avoided by this treatment. (*Oil, Paint, and Drug Rep.*)

All the mineral oils—and also sperm-, lard- and neatsfoot-oils — appear to reach a nearly uniform coefficient of friction at very greatly different degrees of heat in the bearings. Several kinds of the best mineral oils, and sperm- and lard-oils, show a uniform coefficient of friction at the following degrees of heat:—

Temperature at which the coefficient of friction is the same.

Downer Oil Co., 32°, Machinery (an exceedingly fluid oil) ..	76° F.
„ „ Light Spindle	105° F.
„ „ Heavy Spindle	125° F.
Various samples of Sperms	96 to 114° F.
Leonard and Ellis Valvoline Spindle	127° F.
„ „ White Valvoline Spindle	122° F.
„ „ White Loom	111° F.
Olney Bros., German Spindle ..	112° F.
„ „ A Spindle	107° F.
Neatsfoot	170° F.
Lard-oil	180° F.

Lubrication seems to be effective in inverse ratio to viscosity—that is, the most fluid oil that will stay in its place is the best to use. Lard-oil heated to 130° F. (54½° C.) lubricates as well as sperm at 70° F. (21° C.), or the best mineral oil at 50° F. (10° C.). But of course it is a great waste of machinery to work oil of any kind up to an excessive heat; and there must be the least wear in the use of oil that shows the least coefficient of friction at the lowest degree of heat.

The quantity of oil used is a matter of much less importance than the quality. The mill that saves gallons of oil at the cost of tons of coal, or dollars of repairs, plays a losing game. Waite's experiments on very heavy bearings at Manchester go far to prove that a considerable quantity of thin fine oil keeps the bearings much cooler, and requires less power, than a smaller quantity of thick viscous oil. Here let it be observed that a superstition which prevails in favour of using castor-oil to cool a hot bearing is without any warrant. No vegetable oil is fit to use as a lubricant; and castor-oil is the worst of all, because the most viscous. If used, it will surely set the mill on fire, as it did in the only case of which we have a record.

Cast iron holds oil better than any other metal or any alloy, and is the best metal to use for light bearings, perhaps for heavy.

It has been proved by Waite's experiments that a highly polished bearing is more liable to friction than a surface finely lined by filing. The lines left by the file serve as reservoirs for the oil, while the high polish leaves no room for the particles between the metal surfaces.

So far as laboratory experiments may serve as a guide in practice, it therefore appears that fine mineral oils may be made to serve all the purposes of a cotton-mill, and such is the practice in some of the mills that show the very best results in point of economy.

Next, that the best animal oil to mix with a fine mineral oil, in order to give it more body, is sperm-oil; this, again, accords with the practice of many of the mills in which the greatest economy is attained.

Lard- and neatsfoot-oil are used to give body to mineral oil in some of the best mills; but the results of work seem not to warrant this practice, unless there is some peculiarity in the machinery that makes it more difficult to keep a less viscous or tenacious oil on the bearings.

All the mixed oils sold under fancy names we believe must of necessity consist of certain proportions of the oils heretofore named, as none of the vegetable or fish oils is fit to be used, and there are no other animal oils that can be had in any quantity.

It appears that all varieties of mineral oils are or have been used in print cloth-mills, and are all removed in the process of bleaching, as practised in print-works.

All mineral oils stain more or less, and give more or less difficulty to the bleacher when dropped upon thick cloth, or cloth of a close texture. On this point we have been able to establish no positive rule; but as very many kinds are and have been used in mills working on such cloths, and are removed, we are inclined to the belief that this question is not of as great importance as it has been assumed to be. (*Scient. Amer.*)

A writer in *Iron* says:—One of the first effects of friction is to engender heat. It is a singular circumstance that whereas lubricants are intended to prevent friction, many of them are capable, under certain circumstances, of exciting a degree of heat which is fraught with danger. This action takes place, not when the lubricants are in contact with metallic surfaces, but when they are absorbed into certain fibrous or cellular bodies of a vegetable nature. Wood, in the form of sawdust, when impregnated to a moderate extent with one or other of a certain class of oils, is capable of developing spontaneous combustion. The action is still more rapid when the material consists of cotton rags to which the dangerous class of oil has been applied. The phenomenon is evidently one of oxidation, for in the case of sawdust, if the saturation be very complete, combustion does not take place, whereas if the soaking be slight, there is a probability that combustion will ensue.

The test with regard to spontaneous combustion is one which ought on no account to be overlooked. It has no relation to what is termed the "flashing-point" of an oil. Scientific investigation seems to show that oils which have a viscid character are those which possess, in varying degrees, the dangerous property of setting up a high degree of heat under certain circumstances. So far as the flashing-point is concerned, the most volatile of natural lubricating oils will not give off an inflammable vapour at a lower temperature than 200° F. (93° C.). Consequently the vapour cannot come into play until danger presents itself from some other source. As for the risk of spontaneous combustion, the following test has been applied:—Cotton waste, soaked in Rangoon engine-oil, was enclosed in a metallic vessel surrounded by an air-bath having a temperature of 170° F. (77° C.). In 6½ hours the temperature of the oiled cotton had not risen to above 144° F. (62° C.). The gas flame which heated the air-bath was allowed to remain under the vessel for a further period of 17 hours, but no change was produced, except that there was discernible a slight smell, due to the evolution of acrid vapour in small quantity, arising from the slow decomposition of the vegetable part of the oil. The bath was next raised to 190° F. (88° C.), and so remained for 24 hours; but no effect was produced. The temperature of the bath was next raised to 200° F. (93° C.), and left at that point for 6 hours, but the material still remained perfectly quiescent, showing its utter incapability of producing spontaneous combustion.

In contrast with the foregoing, it may be mentioned that cotton soaked with olive-oil (Gallipoli), on being exposed to a temperature of 170° F. (77° C.) for a day and a night, was found, on examination in the morning, to be much charred, the centre portion being reduced to ashes, showing that actual ignition had taken place. In a series of experiments conducted by John Galletly, a quantity of cotton waste was soaked in Gallipoli olive-oil, and loosely packed in a paper box, in size about $\frac{1}{10}$ cub. ft. The box was exposed to a temperature of 130° F. (54° C.). Two trials were made under similar circumstances. In the first, rapid combustion was found to be coming on in little more than 5 hours, and in the second within 6 hours. Remarking on these and similar experiments with other oils (exclusive of the hydrocarbons), Major V. D. Majendie, R.A.,

Her Majesty's Inspector of Gunpowder Works, observes:—"These facts illustrate the grave and urgent character of the risk which exists when oiled cotton waste is deposited, even in very small quantities and for a very short space of time, in moderately elevated temperatures—such temperatures as exist in the majority of factories, in the neighbourhood of a steam-pipe, or under exposure to the sun's rays."

One of the most delicate articles to lubricate is a watch, and special precautions are necessary to be observed in selecting a material, or combination of materials, for this purpose. Some find porpoise-oil to give most uniform satisfaction, though perhaps rather thin for certain parts. To get rid of acid in the oil, the latter should be washed in filtered water, to which a little soda carbonate has been added; after settling, the oil is poured off, and heated to 212° to 225° F. (100° to 107° C.) for an hour or so with constant stirring. The plan of placing lead shavings in oil to neutralize the acid, is thought by some to exert a drying influence. Oil cannot be tested for acidity by the direct application of litmus; but filtered water used for washing the oil will redden litmus-paper if any acid was present in the oil. Crisp thinks that no very fatty oils (neatsfoot, lard) will repay the trouble of washing and refining; and he is of opinion that all oils refined by heat, by evaporation, by alcohol, or by any quick method, though looking clear and bright, have their lasting properties quite destroyed. He declares it is only by a slow process of abstracting the deposits from the oil at 30° to 32° F. (−1° to 0° C.) that a reliable oil can be obtained suitable for watchmakers. Vaseline may be used with great advantage in the priming up of fusees; a small quantity may also be applied to the collet. Oils for chronometers or watches ought (1) to be chemically pure, (2) not to gum or clog, (3) not to evaporate, (4) not to freeze. Before refining, sperm-oil gums; olive-oil is acid, and discolours steel and brass, which acidity is much reduced or annihilated by the washing process; neatsfoot-oil is very hard to get genuine. Rarely can the oil be depended upon that is offered in the market; besides, neatsfoot is a very tender oil, and requires to be filtered at a very low temperature to get rid of the stearine. As an instance of this, a gallon obtained perfectly genuine was quite solid at a temperature of 50° F. (10° C.). Upon putting this gallon into a bag, about 1 qt. filtered through the bag at a temperature of 32° F. (0° C.), which is the only portion suitable for watchmakers, and this portion requires washing and again filtering to get rid of its acidity. This is also about the proportion that can be obtained from olive and sperm oils, yielding about ¼, or 1 qt. per gallon, under the same conditions of obtaining oil under the cold process.

Some hundreds, if not thousands, of formulæ have been propounded for the fabrication of lubricants suited to all needs; the following are selected as examples:—

(1) English railway axle-grease.

	Summer.	Winter.
Tallow . . .	504 lb.	420 lb.
Palm-oil . . .	280 „	280 „
Sperm-oil . .	22 „	35 „
Caustic soda . .	120 „	126 „
Water . . .	1370 „	1524 „

(2) German railway-grease.

Tallow	24·60
Palm-oil	9·80
Rapeseed-oil . . .	1·10
Soda	5·20
Water	59·30

(3) Austrian railway-grease.

	Tallow.	Olive oil.	Old grease.
Winter . . .	100	20	13
Spring and autumn	100	10	10
Summer . . .	100	1	10

(4) French lard. Dissolve 3 oz. shredded indiarubber in 1 gal. finest rapeseed-oil by the application of heat.

(5) Common heavy shop oil. 30 pints petroleum, 20 of crude paraffin-oil, 20 of lard-oil, 9 of palm-oil, 20 of cottonseed-oil.

(6) Frazer's axle-grease is composed

of partially saponified rosin-oil—that is, a rosin-soap and rosin-oil. In its preparation, ½ gal. of No. 1 and 2½ gal. of No. 4 rosin-oil are saponified with a solution of ½ lb. sal-soda dissolved in 3 pints water and 10 lb. sifted lime. After standing for 6 hours or more, this is drawn off from sediment, and thoroughly mixed with 1 gal. of No. 1, 3½ gal. No. 2, and 4¾ gal. No. 3 rosin-oil. This rosin-oil is obtained by the destructive distillation of common rosin, the products ranging from an extremely light to a heavy fluorescent oil or colophonic tar.

(7) Pitt's car-, mill-, and axle-grease is prepared as follows:—

Black oil or petroleum residue	40 gal.
Animal grease	50 lb.
Rosin, powdered	60 lb.
Soda lye	2¼ gal.
Salt, dissolved in a little water	5 lb.

All but the lye are mixed together, and heated to about 250° F. (121° C.). The lye is then gradually stirred in, and in about 24 hours the compound is ready for use.

(8) Hendricks' lubricant is prepared from whale- or fish-oil, white-lead, and petroleum. The oil and white-lead are, in about equal quantities, stirred and gradually heated to between 350° and 400° F. (177° to 204½° C.), then mixed with a sufficient quantity of the petroleum to reduce the mixture to the proper gravity.

(9) Munger's preparation consists of—

Petroleum	1 gal.
Tallow	4 oz.
Palm-oil	4 oz.
Graphite	6 oz.
Soda	1 oz.

These are mixed and heated to 180° F. (82° C.) for an hour or more, cooled, and after 24 hours well stirred together.

(10) A somewhat similar compound is prepared by Johnson as follows:—

	Liquid.	Solid.
Petroleum (30° to 37° gravity)	1 gal.	1 gal.
Crude paraffin	1 oz.	2 oz.
Wax (myrtle, Japan and gambier)	1½ oz.	7 oz.
Bicarbonate of soda ..	1 oz.	1 oz.
Powdered graphite	3 to 5 oz.	8 oz.

(11) Maguire uses for hot neck grease—

Tallow	16 lb.
Fish	60 lb.
Soapstone	12 lb.
Graphite	9 lb.
Saltpetre	2 lb.

The fish (whole) is steamed, macerated, and the jelly pressed through fine sieves for use with the other constituents.

(12) Chard's preparation for heavy bearings consists of—

Petroleum (gravity 25°)..	12 oz.
Caoutchouc	2 oz.

(13) Booth's. ½ lb. soda, 1 gal. rape-seed-oil, 1 gal. water, ½ lb. tallow or palm-oil; mix intimately, heat to boiling, and continue stirring till cooled down to 60° or 70° F. (15½° to 21° C.).

(14) 1 gal. boiling water, ½ lb. Scotch soda, 10 lb. of a mixture of palm-oil and tallow in any proportions; treat as (13).

(15) 10 lb. Scotch soda, 1 lb. glue dissolved in 10 gal. water, 10 gal. oil, 4 lb. indiarubber dissolved in oil of turpentine; add the indiarubber last, and stir the whole thoroughly.

(16) 2½ lb. lard, 1 oz. camphor, ½ lb. graphite ("blacklead"). Rub up the camphor into a paste with part of the lard in a mortar, add the graphite and the rest of the lard, and intimately mix.

(17) Dissolve 2¼ lb. sugar of lead (lead acetate) in 16 lb. melted but not boiling tallow, and add 3 lb. black antimony, stirring the mixture constantly till cold. For cooling necks of shafts.

(18) 4 lb. tallow, 1 lb. graphite, ground together till quite smooth, adding 3 lb. to 5 lb. camphor per cwt.

(19) Railway-grease. — For summer use—1¾ cwt. tallow, 1¼ cwt. palm-oil; for autumn and spring—1½ cwt. each tallow and palm-oil; for winter—1¼ cwt. tallow, 1¾ cwt. palm-oil. Melt the tallow in an open pan, add the palm-oil, and remove the fire the moment the mixture boils; stir frequently while cooling, and when the temperature has fallen to about 100° F. (38° C.), run it through a sieve into a solution of soda

(56 to 60 lb.) in 3 gal. water, and stir together thoroughly.

(20) To a quantity of good lard, rendered semi-fluid (but not liquid) by gentle heat in an iron pan, is gradually added $\frac{1}{5}$ part by weight of finely powdered and sifted graphite (blacklead), with careful and continued stirring till the mass is homogeneous and smooth; the heat is then steadily increased till the compound liquefies, when it is allowed to cool, the stirring having been meanwhile kept up unceasingly.

(21) 8 lb. tallow, 10 lb. palm-oil, 1 lb. graphite (blacklead).

(22) Watchmakers' oil. — Olive-oil containing a strip of clean lead is exposed to the sun in a white glass vessel till all deposit ceases, and the supernatant oil is limpid and colourless.

(23) Oleine for lubricating fine mechanism is prepared by agitating almond- or olive-oil with 7 or 8 times its weight of strong alcohol (sp. gr. 0·798) at nearly boiling-point; the solution is allowed to cool, and the clear fluid is decanted, filtered, and heated to drive off the alcohol. It may further be exposed to a low temperature to deposit any remaining stearine.

(24) Railway- and Waggon-grease.— The first of these consists essentially of a mixture of a more or less perfectly formed soap, water, carbonate of soda, and neutral fat, and is used on the axles of all locomotives, railway-carriages, and trucks that are provided with axle-boxes; while the second is a soap of lime and rosin-oil, with or without water, and is used on all railway-trucks unprovided with axle-boxes, and for ordinary road vehicles.

The requisites for a good "locomotive-grease" for high velocities are: (1) a suitable consistency, such that it will neither run away too rapidly, nor be too stiff to cool the axles; (2) lasting power, so that there may be as little increase of temperature as possible in the axles, even at high speeds; (3) a minimum of residue in the axle-boxes.

In practice, it is found that a grease containing 1·1 to 1·2 per cent. soda (100 per cent.) gives the best result. The process of manufacture is very simple; Morfit's soap-pans, provided with stirrers, are the most suitable vessels for the purpose. The fats, usually tallow and palm-oil, are heated to 180° F. (82° C.), and into them are run the carbonate of soda and water heated to 200° F. (93½° C.); the whole is well stirred together, and run into large tubs to cool slowly. Many railway companies buy a curd-soap made from red palm-oil, dissolve it in water, and add thereto enough tallow and water to bring the composition of the whole to the desired point. It is usual to allow 2½ per cent. for loss by evaporation of the water during the manufacture. The composition has to be slightly varied according to the season of the year; the following formulæ for mixing have stood the test of successful experiment; the summer one ran 1200 miles. It should be carefully borne in mind that a careful analysis of locomotive-grease is no test whatever of its practical value, which can only be determined by actual experiment.

	Summer.	Winter.
	Per cent.	Per cent.
Tallow	18·3	22·3
Palm-oil	12·2	12·2
Sperm-oil	1·5	1·2
Soda crystals	5·5	5·0
Water	62·5	59·3
	100·0	100·0

The "waggon-grease" is thus prepared:—A good milk of lime is made, and run through several overflow-tubs, where all grit is deposited; it is then drained on canvas. If the grease is to be made without water, the paste must be agitated with rosin-spirit, which expels the water, and it is then thinned with a further quantity of rosin-spirit. The aqueous milk of lime, or the mixture of lime and rosin-spirit, is then stirred together with a suitable quantity of rosin-oil, in a tight barrel furnished

with a shaft and stirrers, without the application of heat, after which the whole is run out into barrels to set. Many other ingredients are often stirred in, such as "dead oil," petroleum residues, graphite, sea-weed jelly, silicate of soda, oil refiners' foots, micaceous ores, steatite, Irish moss, &c. (Spons' *Encyclopædia*.)

See also the article "Friction" in Spons' *Dictionary of Engineering*, and "Lubricants" in WORKSHOP RECEIPTS.

MAGNESIUM.—This metal is widely distributed in some of the common rocks; *e.g.* as carbonate in dolomite and magnesite, as sulphate in kainite and kieserite, and in many saline springs; and as chloride in carnallite and sea-water. The metal was first obtained in a compact form by fusing the anhydrous chloride with potassium. Later, Bunsen prepared it by electrolysing the fused chloride in a porcelain crucible, centrally divided by a vertical partition formed of the cover of a similar crucible ground to fit; hanging over this partition is a support carrying 2 poles of retort carbon, the negative one being notched for the reception of the deposited metal, which, being lighter than the fused chloride, would otherwise reach the surface and ignite. Matthiessen avoids the difficulty of preparing the pure chloride by using a mixture of 3 molecules of potassium chloride and 4 of magnesium chloride, together with some ammonium chloride, fusing the mass, and electrolysing without any notches in the negative pole, they being unnecessary here, as the metal is heavier than the fused mass.

For preparing magnesium on the large scale, Caron et Deville's method is mostly used. It is as follows:—A mixture is made of 60 parts fused magnesium chloride, 48 of finely powdered fluorspar, and 23 of sodium. The sodium is cut into little fragments after being carefully freed from oxide and any petroleum adhering to the surface. A porcelain crucible is heated to redness in a furnace, and into it the mixture is thrown; the cover is replaced and held firmly down during the violent reaction which soon takes place. When the crepitations have ceased, the crucible is opened, and discovers a very fluid mass consisting of undecomposed magnesium chloride, of salt resulting from the reaction of the sodium upon a part of the magnesium chloride used in excess, and of calcium fluoride; no particle of magnesium is yet visible, it being disseminated in microscopic globules in the slag. The portions which have attached themselves to the upper part of the crucible are stirred up with the remainder by a clean iron rod. The crucible is drawn from the fire, and left to cool for some minutes; then pure dry pulverized calcium fluoride is thrown in small portions on the surface of the red liquid, so as to hasten the cooling, at the same time that the mass is stirred till it becomes pasty. The metallic globules are thus brought to agglomerate, and if properly performed, by the time the slag has consolidated, all or nearly all the magnesium will have run into one large mass occupying the bottom of the saline fluid. A little of the slag coats the metal and preserves it from oxidation by the air, and ignition; should the latter accident happen, combustion may be stopped by throwing a little calcium fluoride upon the incandescent metal. The crucible is broken when cold, and the metal is chipped out, amounting, with the few little globules scattered through the saline slag, to about $9\frac{1}{4}$ parts, or $\frac{3}{4}$ of the quantity which the sodium used ought to furnish. The slag remaining should be re-melted and re-treated several times, to afford further small quantities of the metal, by which the yield may be brought as high as 45 oz. of crude magnesium for 100 oz. of sodium used.

A modification of this process, which gives good results, is as follows:—The magnesium chloride is prepared by the method just described; 6 parts of this are mixed with 1 of fused salt (or better, of Wöhler's mixture of salt and potassium chloride), and 1 of dry pure calcium fluoride, the whole being previously reduced to powder; 1 part of

sodium in fragments is well mingled with the chloride, and the whole is thrown into a red-hot crucible; fusion and stirring are repeated as in the process just described, and when the metal has been brought together in a single ball, the whole mass is poured out on a stone or iron slab; on breaking the slag, globules of magnesium are discovered and removed, and the slag is re-melted to afford further small quantities. To make ingots of magnesium, the crude pieces are fused with a mixture of magnesium chloride, salt, and calcium fluoride; by somewhat increasing the proportion of this last-named substance, which is gradually added to the melting-pot, the slag is rendered less fusible than the magnesium, so that the metal can be poured into a mould at the moment when the slag sets. Perhaps a better plan is to melt together 60 parts common salt and 75 of potassium chloride (Wöhler's flux), which is run upon a clean iron slab. The cooled mass is broken, and introduced into a hot crucible at the same time as the globules of magnesium, which have previously been carefully cleaned by means of nitric acid. The whole is fused, and soon the magnesium floats on the saline slag; but at the moment when the latter begins to solidify, the magnesium becomes denser than it, and falls to the bottom of the crucible, where it collects in one mass. Even after this operation, the magnesium is not pure, containing carbon, silicon, and nitrogen; to obtain it in a state of absolute purity, it must be distilled.

Wöhler suggests using the fused double chloride of magnesium and sodium, to avoid the trouble of preparing the anhydrous magnesium chloride. Sonstadt proposes a mixture of potassium and magnesium chlorides, which may be obtained by fusing carnallite, carefully avoiding the presence of kieserite, which may cause explosions.

The distillation of magnesium to effect its purity, as alluded to in the last paragraph but one, is thus effected: the crude metal is put into an iron crucible (with an iron tube passing through from the bottom to within $\frac{1}{2}$ in. of the cover) until it is filled to the level of the mouth of the tube, when the lid is carefully luted and screwed down, and the air is displaced by a current of hydrogen or coal-gas. As the crucible becomes heated, the magnesium distils over, passing through the upright tube into a receptacle beneath, where it forms a compact mass that may be melted and moulded as desired.

For the manufacture of magnesium wire, use is made of an apparatus introduced by Mather and Platt, Salford.

Metallic magnesium is employed chiefly as a source of light for fireworks, signals, and photography: $2\frac{1}{2}$ oz. of burning magnesium will afford a light equal to that from 74 candles burning 10 hours and consuming 20 lb. of stearine, and the light is of an intensely white character. The metal has a sp. gr. of 1·75; in dry air it retains its silvery lustre, but in damp air it assumes a coat of oxide; it melts at a red heat, and boils at a little higher temperature than the volatilizing-point of zinc.

MANGANESE.—When the metal manganese was first discovered in 1774 by Frederick Gahn, the celebrated Swedish mineralogist and chemist, in reducing it from the natural oxide in a small crucible, nobody could have foreseen that the identical body, only combined with a few per cent. of carbon and iron, would a hundred years hence, be produced in the largest blast furnaces, and at not very much greater cost than common crude iron. When this greyish-white and very brittle metal was first known, its properties seemed to render it unfit for any practical use, as it required a very great heat for its reduction from the ore, and when exposed to damp air, it would rapidly decay or crumble to pieces. Although the metal was known to exist to some extent in the so-called *spiegeleisen*, and although it was many years ago thought to be essential in the manufacture of the very best German shear steel, nobody

took the trouble to produce metallic manganese on purpose. Oxidized manganese was, however, at an early date, a frequent admixture in the manufacture of ordinary cast steel or crucible steel, and by the Sheffield steelmakers particular cleansing or strengthening properties were attributed to it, in more good belief than reality.

It was only after Valenciennes, in 1870, had succeeded in producing, in a magnesia crucible with a gas-furnace, pure manganese metal in the molten state from pure manganese hyperoxide, and had exhibited this to the French Academy, that fresh attention was directed upon this peculiar and, as is now generally acknowledged, highly useful metal. Thus, Dr. Percy, in 1873, proposed to employ manganese instead of nickel in the manufacture of German silver, an alloy which contains copper and zinc besides. At that time also Tamm was able to produce an alloy of manganese and iron, with 96 per cent. of the former; while at Jauerburg, in Carniola, ferro-manganese, an alloy of iron with carbon and up to 30 per cent. of manganese, had been successfully produced in the charcoal blast-furnace and on a large scale. Since then the production of either pure metal or of its alloys with iron has been attempted by many English and foreign metallurgists, and by the employment of very different methods. The palm must, however, be given to those who have succeeded in producing ferro-manganese, containing 80 to 90 per cent. of the metal, by using the ordinary blast-furnace as a reductor and coke as fuel. Such specimens were largely exhibited at the late Düsseldorf Provincial Exhibition by the Phœnix Iron Company of Ruhrort, and the Gutehoffnungs-Hütte of Oberhausen; while alloys of manganese with copper, zinc, tin, and lead were shown by the Brothers Heusler, of Dillenburg, in Nassau. They are remarkable for their extraordinary strength, toughness, and hardness, which may be produced at will by varying the quantities of the component metals.

When we look at the progress which the production of ferro-manganese—or, as we now may well call it, "crude manganese"—has made during the last few years, we find it to be quite astonishing. The reduction of manganese in combination with iron and carbon was attempted as long ago as 1865 by several metallurgists, such as Prieger, Bessemer, and others, who employed crucibles; and by Henderson, who used the Siemens furnace for this purpose; and while the latter succeeded in getting a compound with about 30 per cent., the crucible process was able to produce an alloy with 60 per cent. of manganese, *spiegeleisen* at that time hardly ever containing above 12 per cent. of the metal. This was the state of the manufacture of manganese compounds when, at the Vienna International Exhibition in 1873, the Krainer Eisen- und Stahlwerks-Gesellschaft, of Laibach, in Carniola, produced specimens of *spiegeleisen* with nearly 20 per cent., and others of ferro-manganese of a far higher percentage, which were then considered as something quite wonderful among metallurgical products. For, as was stated, they were products of the blast-furnace, and very many tons of these compounds could every day be tapped from the blast-furnaces of Jauerburg and Sava.

Though these statements met at first with some incredulity, it was nevertheless confirmed that the technical managers of the company, Von Banz and Luckmann, had indeed succeeded in employing the ordinary blast-furnace, with charcoal as fuel, for the production of the above-named compounds from a mixture of calcined carbonates and hydrates of iron, with manganese ore from Vigunsza. The samples showed the characteristics of *spiegeleisen* up to a content of 20 per cent. of manganese; above this, they lost all crystalline appearance, and became non-magnetic, with an almost homogeneous or fine-grained fracture. Some of these samples, taken at the Exhibition, gave by analysis, in 100 parts—

Carbon ..	5·33	5·31	5·28	5·27
Manganese	22·46	23·48	28·70	35·04

This great success stimulated the

managers of the Reschitza Iron Works, in Hungary, to imitate the process, and after a good deal of trouble they were able to produce, with a slag containing principally lime, manganese, iron, and alumina, and only slightly above 20 per cent. of silica, a compound with over 35 per cent. of metallic manganese. At the same time, in 1874, Jordan, at the St. Louis Iron Works, near Marseilles, also succeeded in getting from the blast-furnace ferro-manganese with 20 to 25 per cent. At Terrenoire the Siemens furnace had been tried, since about 1868, in such a manner that bricks were made from an intimate mixture of calcareous manganese oxide with pounded Mokta iron ore, fine coal, and pitch, which bricks were then burned and strongly heated in the Siemens furnace with an addition of *spiegeleisen*, when alloys with 60 per cent. could be obtained. The blast-furnace process at Terrenoire, has, however, only been in use since 1877; and though over 3 tons of coke are required for 1 ton of ferro-manganese, an alloy containing 72 to 74 and even 80 per cent. of manganese can be now made there, when a very basic and refractory green manganese slag is aimed at.

At the Düsseldorf Exhibition of 1880, the Phœnix Company of Ruhrort exhibited specimens of ferro-manganese from the blast-furnace, made with coke and an extremely basic slag, in which silica is mostly replaced by alumina. They contained from 22 up to 77 and 80 per cent. of manganese, while the Gutehoffnungs-Hütte of Oberhausen was able to show samples containing 75 per cent. of manganese with about 5 per cent. of carbon, and, besides iron, only traces of sulphur and phosphorus.

Such is the present state of manufacture of "crude manganese," which will find a still larger use in the metallurgy of steel the more the basic Bessemer process spreads, as its addition is necessary to restore to the overblown iron the required amount of carbon, and to free it by the aid of manganese from its last traces of sulphur, which are left even after phosphorus is entirely eliminated. The success of the blast-furnace process depends, next to a high temperature, and to an extremely basic slag with very little silica, to an intimate mixture of the oxides of iron and manganese as it is found in the natural carbonate ore or the knebelite ore of Sweden, which is a silicate of equal proportions of protoxide of iron and manganese. Whenever the mixture is artificial, the most intimate contact must be looked for, because the reduction of manganese is much more owing to the action of metallic iron than to that of carbon, the former playing an intermediate *rôle* because it it is easily reduced by carbon, and then helps to render the manganese metallic. (*Sci. Amer. Sup.*)

For the preparation of crude manganese, ores are mostly used which contain the manganese in the form of dioxide (MnO_2) or its hydrate (MnH_2O_3). These compounds are reduced in the blast-furnace, by the rising current of gases, to manganic oxide (Mn_2O_3) or manganous-manganic oxide (Mn_3O_4), a corresponding quantity of carbon monoxide being oxidized to dioxide. This oxidation is accompanied by a considerable development of heat. The high temperature thus produced in the upper part of the furnace rapidly destroys its walls and fittings, causes more fuel to be consumed, and greatly interferes with the proper course of the process; nor can the issuing current of gases be utilized any further, on account of a large amount of carbon dioxide. To obviate these difficulties, Lederer recommends to subject the manganese ores to a reducing process before they are brought into the furnace. Of the two ways in which this can be effected, that one is preferable which consists in exposing the ore to the action of a current of gas containing carbon monoxide at a temperature of about 572° F. (300° C.). The apparatus necessary for this is simple. It requires a furnace in which the ores are brought into contact with the reducing gases, and, as such, a cupola furnace with an inclined sole is best, the gases entering at the

lower end and the ores advancing towards the draught. For the reduction, the gases issuing from the blast-furnace itself are most profitably used, since they have retained all carbon monoxide, if the manganese ores have been prepared in the manner stated. The reduction beginning about 392° F. (200° C.), a special heating arrangement is not even necessary, because the furnace-gases are hotter than the above temperature. At most, at the commencement, the furnace may be heated up by burning the gases in it; afterwards, however, the atmospheric air is to be excluded, so that the gases can exert their reducing action upon the ore. (*Chem. Centr. Blat.*)

MERCURY.—The most important ore of mercury (quicksilver) is the sulphide called cinnabar, identical in composition with the vermilion of commerce. The most important deposits of this mineral are at Almaden in Spain, Idria, New Almaden in California, Amiata in Tuscany, China, and Borneo.

Extraction.—When cinnabar is heated in a current of air, it is decomposed, the sulphur uniting with the oxygen of the air to form sulphurous acid, and leaving the mercury in a metallic state. But owing to the low temperature at which mercury volatilizes, the heat required to liberate the sulphur distils the mercury in a vapour, and necessitates the use of complicated apparatus to effect its condensation to the liquid state.

The oldest cinnabar-roasting furnace still, or till recently, in use is the Bustamenti furnace. In this apparatus, the ore and fuel are charged together into a short vertical shaft, and air is admitted from below and from the side. When the shaft is incandescent, the air decomposes the cinnabar, and the volatile products, sulphurous acid, mercurial vapour, and carbonic acid, pass off through flues into 2 large square chambers, where the gases are somewhat cooled. At some distance is a second pair of chambers, and the two sets are connected by several tubes. These tubes are formed of short joints, and each joint is an earthen vessel, swelling at the middle, and with one end larger than the other, so that the small end of one *aludel*, as these vessels are called, may be thrust into the large end of the next. The joint is made with clay. These composite tubes slope from each end towards the centre, and rest on a foundation of masonry. The mercurial vapours passing through these tubes are cooled down, and the metal is deposited in drops, which, on account of the inclined position of the tubes, run down to the central joint. A small hole in the under-side of the *aludel* occupying that position, allows the metal to escape and collect in vessels set to receive it. So much of the vapour as escapes condensation in the *aludels* passes into the second set of chambers, where another portion is liquefied, and the remainder passes out into the air and is lost.

Besides the metallic mercury, another product is condensed, called "soot." Its composition varies, but it contains flour of mercury — *i.e.* mercury in minute globules; undecomposed sulphide of mercury, for cinnabar is itself volatile, and when air is not brought into contact with it, may be distilled unaltered; calomel, when there has been any salt in the ore; and soot proper, formed by the imperfect combustion of the fuel. This product is collected and worked over by hand with lye to cleanse the minute globules of metal from impurities, whereupon a large portion of them unite to drops, and are thus recovered. The remaining matter is added to the ore at the next charge. The mixing of fuel and ore, as practised in this furnace, has one great disadvantage. If at any time there is more fuel than there should be, too great heat is created, and if there are easily fusible compounds in the ore, such as silicate of iron, a glaze is produced, which in this, as in all roasting, interferes very much with the proper action of the air upon the ore. The *aludels*, too, are somewhat difficult of manipulation, and it is very hard to make the joints between them tight;

no one would now build a furnace on this plan.

The Bustamenti furnace is shown in Fig. 150. On the fireplace *a* is kindled a fire of wood introduced through *b*, the flame of which reaches the cinnabar stacked upon the perforated firebrick arch *c*. The ore is introduced through the openings *f g*; in stacking it, large blocks poor in metal are placed first, next above come smaller pieces of richer ore, and at top are put cakes made by kneading up the "soot" before referred to with clay. The sulphurous and mercurial vapours liberated by the heat escape by the flues *d*, in the side of the furnace, into the condensing arrangement *e*, consisting ordinarily of about 300 *aludels* arranged in 12 separate lines of 25 each, side by side. All but one of each line are placed on an incline as shown; this one is laid horizontally in the centre, and is perforated on the lower side, to enable the condensed mercury to escape into the gutter *h*, leading to suitable receptacles. The uncondensed escaping vapours pass into the chamber *i*, where a further deposition of mercury takes place. The chimney *j* carries off the smoke from

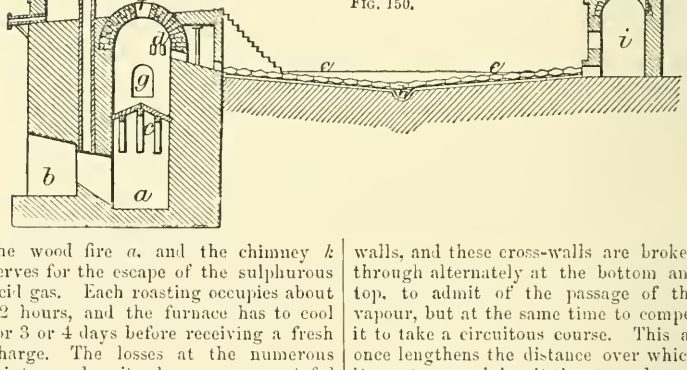


FIG. 150.

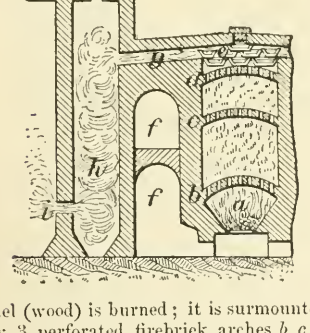
the wood fire *a*, and the chimney *k* serves for the escape of the sulphurous acid gas. Each roasting occupies about 12 hours, and the furnace has to cool for 3 or 4 days before receiving a fresh charge. The losses at the numerous joints render it also a very wasteful apparatus.

The New Almaden furnace consists, in the first place, of a large square shaft, two opposite sides of which are broken through with numerous openings. This shaft is filled with lumps of ore so arranged as to leave passages through the mass, but no fuel is mixed with it. The fireplace is placed on the outside of one of the perforated walls. The flame strikes through the perforations into the ore, and the gaseous products of the process pass through the opposite wall into a series of condensers. The condensers are large chambers of brick, wood, iron, or glass, in which are cross-walls, and these cross-walls are broken through alternately at the bottom and top, to admit of the passage of the vapour, but at the same time to compel it to take a circuitous course. This at once lengthens the distance over which it must pass, giving it time to cool, and, by producing gentle eddies in the current, favours the fall of minute particles of solid or liquid matter. The floors of the chambers are curved, and slope towards the outside wall, so that the metal, as it liquefies, may collect at one point in each chamber, whence it may either be allowed to run out continually through a small opening, or may be tapped when it has accumulated. As the vapour must be cooled down as far as practicable, the natural draught is very slight, and a tall chimney, generally with a small fire in it, is needful to draw in the requisite amount of air through the grate. The working is

very simple. The fire is gradually increased from the start, until, after 3 to 4 days, the mass of ore has come to a moderately bright-red heat, plenty of air being admitted all the time. When this point has been reached, the distillation is considered complete, and the furnace is closed up and allowed to cool. As soon as it is cold, the exhausted ore is removed through suitable openings, and the furnace is re-charged. The necessity of allowing the furnaces to cool down before re-charging involves great loss of time and fuel.

The Idrian furnace is shown in Fig. 151: *a* is the grate upon which the

FIG. 151.



fuel (wood) is burned; it is surmounted by 3 perforated firebrick arches *b c d*, which carry the ore, the largest pieces being stacked on the lowest, and the size decreasing upwards, while the topmost contains shallow stoneware dishes *e*, filled with ore-dust and "soot." Air is admitted to the heated ore through passages *f* in the walls. The sulphurous acid and mercurial vapour pass by 2 chimneys *g* into 6 condensing-chambers *h* on each side, connected alternately at top and bottom (as at *i*), and each provided with a movable lid *k*. The sixth chamber on each side is furnished with means of maintaining a shower of water, to complete the condensation of the vapours. The first 3 chambers on each side catch the bulk of the mercury in a liquid state; this finds its way by a subterranean channel to a reservoir, whence it is ladled into cloth filters, and bottled for export. The last 3 chambers on each side collect solid matters, consisting of a mixture of minute mercury globules, vaporized mercury sulphide, and soot from the combustion of bituminous matters in the ore. The working-off of a charge, and cooling the furnace ready for another, occupies about a week.

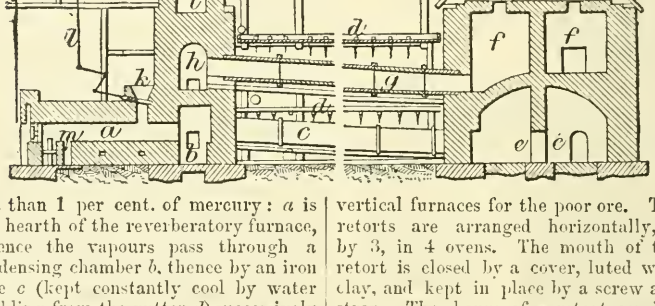
The first furnace devised to allow of a continuous working was the Hähner furnace. In this the ore and fuel are charged together into a shaft, the bottom of which consists of a grate with movable bars. By moving one or more of these bars, the lumps of exhausted ore can be allowed to drop from the furnace, while fresh material is added at the top. The condensation-chambers are arranged as in the Almaden furnace.

The continuity of the Hähner furnace is a great advantage, but not the mixing of fuel and ore. It has consequently been modified so as to resemble furnaces long in use for ores of other metals, by allowing the flame from one or more outlying fireplaces to strike into the shaft filled with ore alone. An important advantage is gained, as in the similar Swedish furnace, by placing the openings for the entrance of the flame some distance from the bottom of the shaft, and allowing the air for roasting to enter at the opening intended for withdrawing exhausted ore. In this way the air is heated by the hot worthless material, and the heat is thus returned to the upper portion of the furnace. The "Knox and Osborne" furnace of California, and the latest furnace of the works at Idria, Southern Austria, correspond to this general description. The former is provided with a single fire, which draws straight across the column of ore in the shaft, and is built of heavy brick walls. The Idria furnace, of which a copy is now putting up at New Almaden, is provided with 3 fireplaces, which draw through nearly ¾ of the height of the column, the gases passing out at 2 openings close to the top of the furnace. The walls are of a

construction first adopted in England for iron blast-furnaces, and since applied with great success to a variety of other furnaces; a comparatively thin lining of firebrick, surrounded by an annular space filled with air, answers admirably as a non-conductor of heat, outside of which is another thin wall of brick enclosed in a shell of boiler-iron. The charging apparatus is also borrowed from blast-furnace construction, and is of the kind called "Parry's bell and hopper." The mouth of a conical hopper is closed by drawing up into it an upright suspended cone. When the hopper is filled, the cone is lowered, and the ore enters the furnace; but its fall is broken by the presence of the cone, and it is thus necessarily distributed in all directions in the furnace. The cone is instantly raised again, and thus shuts off the escape of gas.

Fig. 152 illustrates the improved furnace used at Idria for ores containing

FIG. 152.



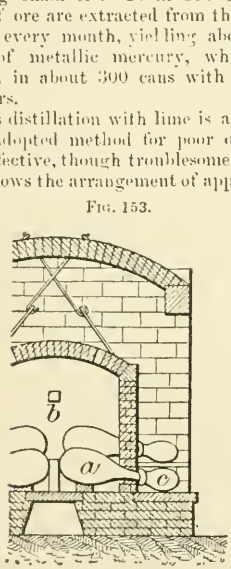
less than 1 per cent. of mercury: *a* is the hearth of the reverberatory furnace, whence the vapours pass through a condensing chamber *b*, thence by an iron pipe *c* (kept constantly cool by water trickling from the gutter *d*) successively into other chambers *e f*, back by another similar pipe *g* into a chamber *h*, and so into the chimney *i*. The hearth is divided into 3 sections, that farthest from the fire receiving the crude ore by means of the hopper *k*, provided with an adjustable damper *l*; the ore is turned over, as the roasting proceeds, in the direction of the fireplace, thus experiencing a growing heat, till, exhausted, it is raked into the well *m*. The liquid mercury is run into suitable receptacles, while the "soot" which collects in the chambers is dried, raked over a sloping table to liberate as much metal as will run free, and finally distilled. The fuel used is wood.

At the Siele works, in the Amiata mountain, Tuscany, the ore is reduced by women into small pieces, which are kept as dry as possible. The works have 12 half-moon retorts of cast-iron for treating the rich ore, and 3 vertical furnaces for the poor ore. The retorts are arranged horizontally, 3 by 3, in 4 ovens. The mouth of the retort is closed by a cover, luted with clay, and kept in place by a screw and strap. The charge of a retort consists of 2 to 2¼ cwt. of ore and quicklime, in the proportion of 1 of the latter to 8 of the former. The retorts are charged every 8 hours, and this operation must be performed very quickly, as distillation begins at once. If the retort be not closed directly, there is great loss of metal, and the men's health suffers through the mercurial vapours. The distilled mercury escapes by the neck of the retort, and passes into a receiver in which cold water is constantly circulating. The mercurial vapours from the 6 retorts are condensed in one and the same tank filled with cold water; and the metallic mercury is drawn off from inclined channels at the bottom. The retorts, fired with wood, of which a large quantity is consumed, only serve for the rich ore; the poor is treated in the 3 vertical furnaces, which are 13 ft. high by 3¼ ft. in diameter. Each furnace is closed at the top by a

hopper with 2 doors, the upper of which has a water joint; 12 charges are made a day, and care is taken to open the upper door as little as possible. At the bottom of the furnace is a grating with movable bars. The charge consists of 2 cwt. of ore, mixed with $\frac{1}{4}$ the quantity of charcoal. The charge is only lowered into the furnace by opening the lower door, while the upper one is closed; and a fire is kept burning at the upper part of the furnace for preventing the escape of the gases. The mercurial vapours and gases of combustion are led by a chimney into condensing chambers. From 150 to 160 tons of ore are extracted from the Siele mines every month, yielding about 22 tons of metallic mercury, which is packed in about 300 cans with screw stoppers.

This distillation with lime is a generally adopted method for poor ores, as it is effective, though troublesome. Fig. 153 shows the arrangement of apparatus

Fig. 153.



adopted on the Rhine. About 30 pear-shaped cast-iron retorts *a* are placed in a gallery-furnace *b*, treated by the vapours from a single coal fire running throughout the whole length, but not in contact with them. Each retort is $\frac{3}{5}$ filled with about 70 lb. of a mixture of $\frac{4}{5}$ ore and $\frac{1}{5}$ quicklime, and its mouth opens into a stoneware vessel *c* containing water. The "black mercury," consisting mainly of finely divided metal and undecomposed sulphide, collected here, is dried and re-distilled. The action of the lime (calcium oxide) is mutual decomposition with the cinnabar (mercury sulphide), yielding metallic mercury in vapour, and leaving behind a deposit of calcium sulphide, partially converted into sulphate by excess of oxygen. The process is wasteful and inconvenient, from the numerous joints and small working capacity. The pear-shaped retorts may be advantageously replaced by gas retorts of 10 times the capacity.

A very crude and wasteful practice is current in Hungary for recovering the mercury from grey copper ore by preliminary roasting before smelting for copper. The ore is burned in mounds 40 ft. long, 20 ft. wide, and 4 ft. 6 in. high, built as follows: a patch of ground is covered with a bed of small ore, followed by a layer of larger lumps which have already been once roasted; next comes a spreading of fuel (coal and wood), and then more ore, finishing at top with a covering of finely powdered ore to check the draught and condense the mercurial vapours. Combustion is supported by channels left in building the mounds; and the heat generated by the fuel ignites the sulphur in the ore, and thus hastens the decomposition. When a mound has burned in this way for about 3 weeks, the upper layer, containing the condensed mercurial vapours, is washed to recover the metal.

The condenser of a mercury-roasting furnace forms of course an exceedingly important portion of the structure, and no absolutely satisfactory construction has thus far been hit upon. Brick is a porous material, and mercury both filters through it and is absorbed into it by the almost resistless force of capillary attraction. Some years ago, in pulling down an old furnace at New Almaden, it was found that the metal had penetrated the foundation and the earth for over 30 ft., and down to the bed-rock. Since then the furnaces have been built on arches, and in the

pillars on which the arches rest sheet-iron plates have been placed to intercept the metal in its downward course; much metal, however, undoubtedly penetrates the outer walls of the condenser, and is evaporated from the surface, for mercury evaporates, more or less, at all temperatures above the freezing-point of water, and the condensers, though built of a very considerable thickness, are of course somewhat warm on the outside. On the other hand, the thicker the condenser the less does the vapour inside cool; and as it must cool to condense, the necessity for thick walls renders a large number of condensing chambers indispensable. It is natural, therefore, to seek some material better adapted to the work required than brick. Cast iron and wrought iron answer very well for condensers, so long as the gas is hot, but when the temperature falls below the boiling-point of water, a very disagreeable action sets in. Sulphurous acid, heated with air in contact with highly porous substances, is partially converted into sulphuric acid; this condenses with the water, and attacks and soon destroys the iron. Wood withstands this action tolerably well, and does not let mercury through like brick, and it has consequently been much used for the later condensers of the series; but wood is a non-conductor of heat, and hence, properly speaking, ill-adapted for cooling apparatus. At New Almaden glass is found to answer excellently, being a much better conductor of heat than wood, though not so good a one as iron, and being of course quite unaffected by the acid liquors. The condensers assume a great variety of forms, such as chambers of various shapes, and tubes. Columns of coke are also used with some success as a final conductor. The draught is sometimes kept up by the aid of a chimney, with or without the help of a fire, to give the air in the stack additional buoyancy, and sometimes by a suction-fan, or a "water-drum," an apparatus which sucks in air by means of the friction of a jet of water. So far as the condensation is concerned, an artificial blast would be preferable, but the danger of blowing jets of the metallic vapour through fine cracks in the apparatus would be too great to admit of its employment.

The losses in mercury-smelting are various and very important, though they are not all well understood. The whole bulk of gas passing out of the last condenser is saturated with mercurial vapour. The amount of metal contained in this vapour depends on the temperature, and for low temperatures is very small per cub. ft., but its aggregate amount per day is by no means inconsiderable. Another source of loss is the fine dust of mercury suspended in the gas, minute globules so small that they fall very slowly through the air, and are therefore carried away in the current of gas. The rate at which a spherical body falls through the air depends upon its specific gravity and its size, and we have therefore only to make a globule small enough to give it a permanent velocity of 10 ft. or of 1 ft. per second. As the mercurial vapour is cooled in the condensers, the mercury is separated out like mist, and the individual globules, which are too small to fall rapidly, and which do not collide and aggregate with others, are, to a great extent, carried off as a dust. Nothing is more difficult than to filter very fine dust effectually on a large scale from a current of gas, as has been proved over and over again in the attempts made to catch the fume from silver-smelting furnaces. How much such fume is formed in mercury-smelting must depend on various circumstances, but the formation of soot in the conductors is sure to be accompanied by a loss in this way, for the metal which is separated out at the same time as the soot, will to some extent be coated by non-metallic impurities, and rendered incapable of running together into larger drops.

Refining.—As a general rule, mercury in its crude imported condition needs refining for use. This may be known by its "tail"-ing, or leaving streaks

where the globules are rolled over a glass surface. The impurities (lead, bismuth, and zinc) are sometimes eliminated by re-distillation. A better and simpler plan for small quantities is to shake it up with powdered sugar in the presence of air, whereby the foreign metals are oxidized to a grey powder, and removed by filtration through perforated paper. The best refining process is washing the metal in a thin layer with dilute nitric acid (1·15 sp. gr.) for a couple of days, with frequent agitation. The acid dissolves out the undesirable metals as nitrates, and may be used several times before its energy is exhausted. The cleansed mercury is washed (with clean water) free from acid, and dried, first with bibulous paper and then by gentle heating. Mechanical impurities can be separated by filtration through perforated paper.

MICA.—Mica is composed of silex, alumina, and potash. It is found in America, Switzerland, Siberia, Norway, Bohemia, and Russia. Siberia and the United States probably furnish the best and largest specimens. It occurs in granite and quartz, also in rubellite, green tourmaline, felspar, lepidolite, and several other minerals. It is one of the constituents of granite, gneiss, mica-schist, talc-slate, &c. It sometimes occurs in granular limestone, and rarely in lava, dolomite, and magnetic iron ores. According to Dana, mica is usually in thinly foliated plates or scales; colour from white, through green, yellowish, and brownish shades, to black; with a pearly lustre, transparent or translucent; before the blow-pipe infusible, but becomes opaque white. There are a number of varieties. That in which the scales are arranged in plumose form is called plumose mica; that in which the leaves or scales have a transverse cleavage is called prismatic mica. The crystals are chiefly rhombic, or six-sided, though not always. The cleavage of mica is highly perfect, and, according to Prof. Henry, it can be split or divided into leaves, 250,000 to the inch. The uses of mica are various. Diamond dust, with which ladies powder their hair, is ground mica. The costly French silver mouldings are cast from ground mica. The wonderful showers of diamonds in scenic plays are mica scales. As a lubricator, mixed with oil it wears longer than any other ingredient. For stoves, it has now become indispensable, and the demand for clear, transparent mica is rapidly increasing. Large plates, when they could be procured, were at one time used in the Russian naval vessels for deck or dead lights, because not liable to fracture from concussion. It is in common use for lanterns, and is rapidly coming into use for lamp chimneys. On account of its transparency and toughness, and the thinness of its folia, it has been used as glass in Siberia, but is now too costly for common use. Sizes as large as 14 in. have been found in North Carolina, and not unfrequently 18 to 24 in. One block or crystal weighed fully 100 lb. Crude mica (pieces too small for cutting) and the cuttings are too far from market, and the uses of waste mica are too limited, to render them valuable. Sizes less than $2\frac{1}{2} \times 4$ or $4\frac{1}{2}$ in. are hardly worth saving. Sizes 5×7 and 9 in. are worth 27*s.* to 30*s.* per lb., with a rapid increase in price for larger sizes. (Cary French.)

The minerals which form the group of micas divide readily into 2 classes: those which are silicates of alumina and an alkali, and those which are silicates of magnesia. They are all notable for their lustre and for their distinct cleavage, which permits of their being separated into thin sheets. In granite, the plates are rarely of a useful size, although in the coarser descriptions of that rock plates are occasionally found 1 ft. and more in width; but in limestone formations, mica is often found in masses of considerable size, plates having been met with in Siberia several ft. in diameter. The micas chiefly occurring in commerce are muscovite and lepidolite (or lithia-mica) of the first division, and phlogopite (rhombic mica) and biolite of the latter division, or magnesian micas. Of these, the most exten-

sively used in the arts are muscovite and phlogopite. The former is mainly a silicate of alumina and potash, with traces of iron, fluorine, chromium, &c., which impart colour to the otherwise grey or silver-white plates of mica. The crystals of muscovite are usually 6-sided—the colour varying from black through grey to green, chromium being invariably present in the crystal of the last-mentioned tint. This variety of mica is proof against acids, is very refractory, the thin edge only fusing before an ordinary blowpipe, while the laminæ are very tough and flexible. Phlogopite, or rhombic mica, as it is sometimes called, is mostly found in limestone, and is composed mainly of silica, alumina, and magnesia, with traces of iron, potash or soda, and fluorine. Its colour varies from brown, through brownish yellow, to grey. If it is previously reduced to fine powder, it is attacked by hot sulphuric acid, but, like muscovite, although it whitens in the blowpipe flame and fuses on the thin edges, it is virtually refractory to anything short of an intense heat. These extraordinary properties, combined with toughness and elasticity, and the peculiar facility with which it splits into thin sheets, some of which approach closely to transparency, led naturally to the use of mica for windows, and especially to its employment in lanterns. For many years it has been used in Russia for windows, and in some parts is still to be found, though it is of course rapidly giving way to the more transparent glass. So common, however, was its employment for this purpose at one time in Russia, that it was frequently called "Muscovy glass." It is found in Siberia, Sweden, and Moravia, which also supply the lepidolite, or lithia-mica. In America it is found in various parts, as North Carolina, New Jersey, and Canada. In some coarse granitic rocks of the first-named state, the mica is found in considerable abundance, and there are unmistakable evidences that it was worked many years ago. The commercial value of mica varies through a wide scale; the large, sound, and clear sheets being naturally the highest priced, fetching as much as 40*s.* a lb. In the United States, where large quantities are used for what is called "stove glass," that is, for the fronts of gas and other stoves, the utilization of mica has been carried further than in this country. The small and waste stuff is there made into a coarse powder, and sprinkled over tar in roof-making; finely ground, it is used as a lubricant, and is sometimes used in packing deed-boxes and safes to render them fireproof. The finer sheets are used for such purposes as the dials of compasses, for the letters of fancy signs, and the very finest and thinnest pieces are sometimes employed in lieu of enamel for covering photographs; but one of the principal uses to which the better qualities are put is the construction of shades for lamps, the nature of the material rendering its decoration a comparatively easy process; chromo-lithography being extensively employed in this manufacture. The preparation of the mica is very easy. When first obtained, it is in plates and crystals of various sizes, from $\frac{1}{4}$ in. to even occasionally 1 ft. in thickness, and from 6 in. to 1 ft. and upwards in diameter. These plates are dull and opaque, and when taken to the workshop they are split sufficiently thin to render them semi-transparent, when they are examined for flaws, and sorted into different qualities. The comparatively thick plates are then taken by the workman and split into the thinnest sheets, a stout knife and skill being all that is required for the purpose. These thin laminæ are easily cut with a pair of shears into any desired form, and are then ready for any further process necessary to fit them for the purpose for which they are intended.

The facility with which they can be bent into various shapes, and the power they possess of resisting heat, together with their transparency and naturally beautiful appearance, make these thin sheets of mica of peculiar value in many situations. They have been used as reflectors for some years, and a patent

has recently been obtained in this country for an improved process of silvering plates of mica, the inventor being a resident of Philadelphia. The flexible nature of the material to be silvered will probably ensure its introduction into the arts and industries to a greater or lesser extent, and it is perhaps not impossible that it may be employed in the manufacture of telescopes, although it must be confessed that its utilization for that purpose is rather improbable. In the process recently patented, sheets of mica, as free from metallic deposit as can be obtained, are thoroughly washed in nitric acid, and then rinsed in water. They are then placed upright in suitable vats or baths, being arranged in pairs, back to back, so as to expose only one side to the coating solution. This latter is tolerably well known, and is made by dissolving 1 oz. nitrate of silver in 1 qt. distilled water, and in a separate vessel 1 oz. glucose in 1 qt. distilled water. When the silver has dissolved, a small quantity of liquor ammoniæ is added, and the solution becomes cloudy, the cloudiness disappearing on the addition of a little more ammonia. When this stage has been arrived at, the 2 solutions are mixed together and poured into the bath containing the mica plates, the bath being placed in a warm room, to facilitate the deposition of the silver. When the mica plates are sufficiently coated, they are withdrawn from the bath, thoroughly rinsed in water, and stood away to dry, after which they may, if deemed necessary, be coated with spirit varnish.

The mica plates thus prepared may be mounted on frames of tin, sheet-iron, paper, or plastic composition. Many other applications of these mica reflectors will suggest themselves, though their principal use is undoubtedly for illuminating purposes. The inventor of the process claims the right of constructing reflectors and shades in the manner described, but, inasmuch as the method of silvering is certainly old, and reflectors made of mica have been known for years, we doubt whether he could succeed in upholding the validity of his patent. (*Eng. Mech.*)

In India, small fragments of mica are largely employed in the tinsel decoration of temples, palaces, banners, &c. In powder, it is used for ornamenting pottery, and even the clothes of the natives. By native artists it is much in vogue for painting on. Although mica is one of the most widely distributed minerals in India, its occurrence in plates of sufficient size to be of commercial value is limited to a few particular tracts. All the mica which occurs in rocks other than those of crystalline or metamorphic character is fragmentary or detrital, and of no substantial value, though it is collected to a small extent by the natives for ornamental purposes. The plates of useful size are found generally in veins of coarsely crystalline granite.

In the year 1826, large transparent laminæ were procured a few miles to the east of Hazaribagh station. In 1849, Dr. McClelland described the mica mines at Dhanwi, Dhoba = Dhunbhar (?) and Quadrumma. At Dhanwi the mica is said to occur in strata alternating with coarse gneiss. The plates are associated with large crystals of felspar and amorphous masses of quartz. About 50 to 100 men and boys were engaged in the mines, which were inclines running with the dip; and as many more women and children occupied themselves with sorting and dressing the plates.

At Dhub and at Jamtara, in the Kharakdiha pargana, are mica mines which have been described by Mallet as follows:—Having given the geological relations of the granite dykes, which he considers to be truly intrusive, he says that the coarsest pegmatite is frequently found in dykes of moderate thickness, in which therefore plates of the largest mica occur, and it is such dykes that the miners generally select for their operations. They pay 1 to 2 rupees each per annum, according to the richness of the yield, to the owner of the land for the privilege of mining. The usual mode of working is simply to excavate a trench along the course of

the dyke, which in the Gawan neighbourhood is seldom carried deeper than 20 or 25 ft. Sometimes, where a considerable thickness of decomposed mica is near the surface, rude shafts are sunk to the fresh and uninjured mineral, and excavations are carried on laterally from the bottom. In a few cases also, rough horizontal galleries are driven in from the side of a hill. In the last methods, of course artificial light is necessary. No precautions are taken to support the roof, and accidents are not unfrequent from its falling in. The plates of mica are generally brought to the miners' villages, and there, after being slightly trimmed with ordinary grass-cutting knives, they are sorted into different heaps according to quality and size. The quality depends on the mineral being in a perfectly unaltered condition, on its transparency and freedom from cloudiness caused by internal foreign matter, on the absence of minor cleavages which render it liable to split into ribbons and triangles, and on the planeness of its fissile surfaces. Six kinds are recognised, according to the size of the plates, viz. (1) *sanjhla*; (2) *manjhla*; (3) *rasi*; (4) *karra*; (5) *urtha*; (6) *admalla*. Some of the miners interpolate *failurtha* between the fifth and sixth, and speak of another size, *barka*, still larger than *admalla*. All these terms are used rather vaguely in respect to the absolute size of the plates indicated thereby. At Dhub and Jamtara the miners were induced to separate a quantity of the mica into the different grades; measured average specimens of each gave the following results:—

	Dhub. Inches.	Jamtara. Inches.
Sanjhla . .	5 × 4	4 × 3
Manjhla . .	7 × 5	5 × 4
Rasi . .	9 × 6	6 × 5
Karra . .	12 × 9	8 × 6

The above 4 sizes include the greater portion of the mica found, it being only in the best mines that *urtha* and *admalla* are procurable. The largest plates which were seen measured 19 × 14 in., and 20 × 17 in., but considerably larger ones are sometimes obtained. The mica is sold by the load, which is built up of plates, either into one frustum of a cone, and carried on the head after being bound together with a cord, or in two such, and carried in a *banghi*. A load equals 6 *panseries*, one *panseri* being equal to 5 *kachcha seers* of 12 *chittacks* each, or $3\frac{3}{4}$ *pakka seers* of 16 *chittacks*; the load, therefore, being $22\frac{1}{2}$ *seers*, or 46 lb. avoirdupois. The miners stated that the prices paid to them per load by the *mahajans* were as follows: *sanjhla*, 3 annas; *manjhla*, 5 annas; *rasi*, 7 annas; *karra*, 12 annas; *urtha*, rs. 2 to rs. 5; *admalla*, rs. 4 to rs. 9; the selling prices being about double these figures. The value of the large plates more especially varies greatly with the quality. According to Colonel Boddam, plates of first quality of 18 in. diameter fetch as much as rs. 60 a *maund* in the market, or about rs. 30 a load. Within the past few years some attempts have been made by a European to work some of these mines, but with extension of the operations the trouble and expense caused by water have increased so much that the work has, it is believed, been abandoned. (Ball, *Economic Geology of India.*)

MOLYBDENUM.—This metal occurs sparsely in many iron ores, and passes into the slag and the pig-iron in the smelting; but it is found much more abundantly in molybdenite (molybdenum sulphide) and in wulfenite (lead-molybdenum oxide), and is met with as a native trioxide (molybdic ochre). Metallic molybdenum is prepared by heating the trioxide or a chloride to redness in a current of hydrogen; the trioxide is not easily reduced, and the product requires to be afterwards heated in a current of anhydrous hydrochloric acid. The pure metal dissolves rapidly in hot concentrated sulphuric acid, in nitric acid, and in aqua-regia, but is insoluble in dilute sulphuric and hydrochloric acids and in hydrofluoric; it oxidizes only when heated in contact with the air, and is infusible in the highest heat of a blast furnace; it has a sp. gr. of 8·6, and a silvery colour,

NICKEL. *Ores.*— The principal ores of nickel are magnetic nickeliferous pyrites, nickel arsenides (especially kupfer nickel, and nickel arseno-sulphide or grey nickel), and the hydrosilicates of nickel and magnesia.

The first-named ore is simply magnetic pyrites containing a certain proportion of nickel sulphide, and is one of the most important. It is met with in Spain, Sweden, Scotland, Piedmont, and the United States. The nickel yield of this kind of ore is usually very small. That from Val Sesia (Piedmont) contains about $1\frac{1}{2}$ per cent. nickel; that from Sagmyra (Sweden) about $\frac{1}{2}$ per cent.; those from Scotland, 7 to 22 (rarely) per cent.; while the celebrated Gap mine, in Lancaster Co., Pennsylvania, which supplied all American wants, and even contributed to European supplies for many years, affords an ore containing only 3 per cent. of nickel, and very difficult to work.

Kupfer nickel is less abundant but richer than the preceding, and occurs in veinlets, especially in Scotland and Saxony. The percentage of nickel varies from 20 to 30.

Arseno-sulphide or grey nickel is met with more particularly in the Harz, Sweden, and Styria. The percentage of grey nickel, corresponding to the formula Ni_2AsS_2, is 35·48.

The hydrosilicates of nickel and magnesia are obtained chiefly from New Caledonia, and carry about 10 per cent. of nickel.

Processes of Extraction.— The processes employed in obtaining nickel differ widely, according as it is derived from the sulphuretted or arseniuretted ores commonly found in Europe, or from the oxidized ores of New Caledonia. For the former, the first step is the elimination of the two metals nickel and cobalt in an intermediate product called "matte" or "speiss," according as the original ore was a sulphide or an arsenide; these products are then gradually concentrated by a succession of roastings and fusions; finally, there remain oxides of nickel and cobalt, which are reduced in a closed retort. For the New Caledonian ore, the most interesting of the methods employed is related to the metallurgy of iron: the initial operation is to make a pig of iron and nickel, followed by a refining process on the hearth of a reverberatory furnace, to remove the foreign matters and give pure nickel.

Treating Sulphides.—By sulphides are understood magnetic pyrites containing small proportions of the sulphides of nickel and cobalt, with 50 per cent. of gangue. In treating this ore by the dry method, the following observations have been made:—(1) In the presence of an acid silicate, the nickel sulphide is not nearly decomposed, while the cobalt sulphide is so completely, and a part of the cobalt is lost in the slag; (2) run down with a material containing sulphur, the nickel oxide is decomposed, and all the nickel combines with the sulphur, while with the cobalt oxide the reaction is only partial; (3) under the same conditions, that is to say in contact with sulphur free or combined, nickel silicate is only partially decomposed, cobalt silicate not at all. Consequently, the object must be to slowly oxidize the matters other than the nickel and cobalt, so that they can be easily removed in the cinder, while the nickel and cobalt are retained by the sulphur in the mattes formed; but care must be had to avoid the oxidation of these 2 metals, and especially their silication. The first roastings are generally effected in stalls; the oxidation is achieved by preference on the hearth of a reverberatory furnace. The roasting is much more moderate according as there is more cobalt, and greater care is needed to avoid scorification. The first fusions are made in a blast furnace, and the last in a reverberatory.

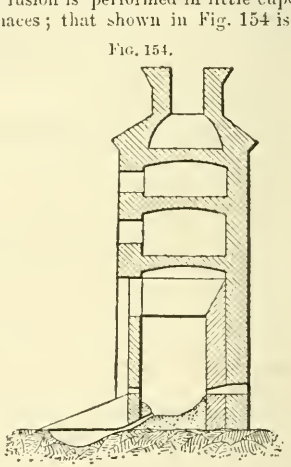
The Sagmyra works, in Sweden, treat very poor ores, containing 0·6 per cent. nickel and 0·7 copper. The roasting of the ores is done in pyramidal heaps of 300 to 400 tons, and lasts 3 to 4 weeks. The first fusion takes place in a blast furnace measuring 12 ft. high between the level of the twyers and that of the

throat; the section is trapezoidal; 3 twyers are placed in the rear wall and 1 in each of the lateral ones, making a total of 5; a sixth opening is reserved in front for withdrawing the slag and tapping the matte; this last has a mean richness of 4 per cent. nickel and 4½ copper. Next comes another roasting; the first matte, in masses of about 25 tons, is put through 4 or 5 fires, the object of which operation is to oxidize a fresh quantity of foreign metals. This result is not attained without the nickel and cobalt also oxidizing a little, but, as scorification is avoided, the reduction of the oxides thus formed is readily achieved. The roasted matters are smelted in another blast furnace 10 ft. high, with a closed breast: the new matte contains about 25 per cent. nickel and 25 copper. The second enriched matte is granulated at the moment of running out, then roasted in a reverberatory furnace; the roasting lasts 24 hours, and the heat is furnished by the gases of the blast furnace of the first fusion. A final fusion on the hearth of a reverberatory furnace gives a matte holding 35 per cent. nickel, 40 of copper, and less than ½ of iron. Efforts have been made to suppress the second roasting and second fusion; in that case the first matte is granulated and treated with weak sulphuric acid, by which a great part of the iron is dissolved out, and but little of the nickel, thus separating the iron and nickel; but the process has the inconvenience of producing a great quantity of iron sulphate, which is not always marketable.

Treating Arsenides.—Arsenides, like sulphides, are subjected to a series of roastings and fusions: the nickel and cobalt are at once united by the first fusion in a new product termed "speiss," a complex mixture of arsenides formed with all the metals contained in the ore; the nickel and cobalt are then concentrated in the speiss by freeing this latter of the more oxidizable metals which it contains. To regulate these operations, regard is had to the following peculiarities: — (1) Arsenides of nickel and cobalt, in presence of slag having 33 per cent. of iron oxide, scarcely yield any nickel or cobalt; (2) nickel oxide fused in the presence of arsenic or mispickel is entirely decomposed, the nickel uniting with the arsenic—this only partially takes place with cobalt oxide; (3) nickel silicate fused in presence of free or combined arsenic is partially decomposed, but cobalt silicate is much less attacked.

From the preceding considerations, the roastings are conducted in a manner to avoid oxidation, and especially silicatization, of the nickel and cobalt. In general, reverberatory furnaces are used for the roastings; but for rich speiss, the first roastings are done in heaps. The fusion is performed in little cupola furnaces; that shown in Fig. 154 is of

FIG. 154.



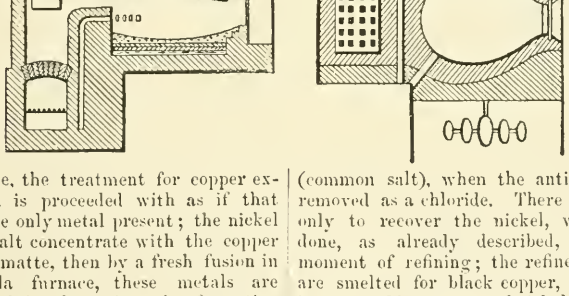
the form employed at Hopfriesen. The speiss once concentrated, the fusion is sometimes exchanged for a roasting in a "Hungarian" furnace, as illustrated in Fig. 155. Sufficient concentration is generally attained after 3 successive series of roasting and fusion; the table below, taken from the experience of the Georges works near Dobrina, in 1876, gives an example of the progressive character of the speiss; but sometimes the final richness is pushed as far,

as 65 to 70 per cent. of nickel and cobalt :—

	1st Speiss.	2nd Speiss.	3rd Speiss.
Nickel and cobalt	20·7	31·9	50 to 52
Copper . . .	1·6	1·9	1 „ 2
Iron	44·3	26·4	8 „ 10
Arsenic . . .	21·3	36·3	38 „ 40
Sulphur . . .	10·2	3·1	1 „ 2
	98·1	99·6	

Treating very poor Ores worked for other Metals.—The preceding remarks refer only to ores which are sufficiently simple and rich to be worked chiefly or perhaps exclusively for their nickel and cobalt ; but it is sometimes desirable to recover these metals from intermediate products which have been the chief consideration in treating the ore. For example, copper ores are met with containing so little nickel and cobalt as not to be worth dealing with for the direct extraction of these 2 metals. In this case, the treatment for copper extraction is proceeded with as if that were the only metal present ; the nickel and cobalt concentrate with the copper in the matte, then by a fresh fusion in a cupola furnace, these metals are separated by favouring the formation of a speiss in which the nickel and cobalt are contained. To achieve this it may be necessary to add some sulphur or arsenic to facilitate the formation of the several compounds.

FIG. 155.



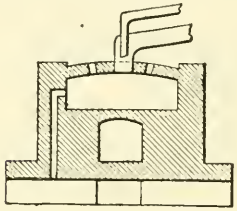
The poor ores thus treated are generally very complex, and contain at once antimony and arsenic. The antimony must be signalized as likely to cause certain difficulties : for example, after having separated the copper in the form of a matte, there often remain in it a little nickel and antimony. When the nickel is alone, its elimination is still sufficiently easy towards the end of the refining ; but if antimony is also present, it is difficult to avoid the formation of a double antimoniate of copper and nickel, which successive roastings cannot get rid of ; it is then necessary to add a little sodium chloride (common salt), when the antimony is removed as a chloride. There remains only to recover the nickel, which is done, as already described, at the moment of refining ; the refinery slags are smelted for black copper, containing up to 30 per cent. of nickel.

Treating Matte and Speiss.—The matte or speiss, once prepared as above described, the next object is to obtain the oxides of nickel or cobalt. To accomplish this, either the dry or the wet method may be pursued, according as the proportion of cobalt mixed with the nickel is great or small.

(1) Dry Process.—When the foreign matters present in the matte or speiss are only sulphur, arsenic, and antimony, simple roasting conducted with care suffices to eliminate them by the formation of volatile oxides, yielding the nickel oxide nearly pure. The speiss may also be treated with soda nitrate, which produces alkaline arseniates and antimoniates easily removable by washing. The presence of copper does not increase the difficulty ; after the roasting there remains a mixture of copper

and nickel oxides, which furnish, finally, a marketable alloy of the 2 metals. As to the separation of the nickel and cobalt, if the proportion of cobalt be small, advantage can be taken of its superior oxidizability; if the cobalt is abundant, recourse must be had to the wet way. The roasting alluded to above is performed on the hearth of an ordinary reverberatory furnace, or in more complicated special furnaces, such as those at Sagmyra, Sweden, shown in Fig. 156.

FIG. 156.



The materials, granulated mattes, are charged through the openings in the arch; they are roasted by the oxidizing flame of a sort of blow-pipe entering at the centre; and the oxide vapours escape by the lateral flues which descend into a pit. The roasted matters are removed in trucks, into which they fall through apertures in the sole of the furnace.

(2) Wet Process.—Mattes or speisses containing both nickel and cobalt in some considerable quantity, are first roasted, and then dissolved in hydrochloric acid, with or without the addition of nitric acid. If there is much iron, the solution is evaporated, and the residue calcined to remove a portion of the iron in the state of a chloride, taking up again in water; thus, on adding lime carbonate, the remainder of the iron, as well as some copper and arsenic, is precipitated; finally, the cobalt is removed in the state of sesquioxide by means of lime chloride and carbonate, and the copper and nickel are generally precipitated together as oxides by the lime.

Preparing Metallic Nickel.—The oxides once obtained, either by the dry or by the wet way, it remains only to reduce them. With this object, they are mixed with a little meal and water, and made into a paste, which is cooked and cut into cubes measuring about ½ in. on the face; these cubes are then strongly heated in contact with pulverized wood charcoal. Generally the metal does not fuse, though the melting-point of copper may be reached and surpassed: it retains the form of little cubes, and is thus met with in commerce, when it has been obtained from arsenical and antimonial ores; but it is then never quite pure. (Badoureau.)

Nickel ores mostly come to this country for reduction after having undergone a process of "concentration" abroad. They come here either as a matte — a combination of nickel, cobalt, copper, and iron with sulphur; or as a speiss—a combination of the nickel and copper with arsenic. In the preparation of nickel from the matte or speiss, nuisance is apt to arise. The earlier steps in the reduction of the matte or speiss consist of processes very similar to those employed in the smelting of copper. The objects sought are the further concentration of the material, *i.e.* the separation of iron from it by alternate calcination and melting, by which the iron is slagged off; and then the conversion of the valuable metals present into oxides or soluble salts. The calciners and melting furnaces used are similar in construction to those employed in copper smelting, and for the oxidation of the nickel, &c., free access of air is given in the last process. The product of the last operation at the furnaces is then subjected to a series of wet processes. It is first dissolved, by the aid of steam, in water to which hydrochloric acid is added in sufficient quantity, and then the iron present is precipitated from the solution by means of milk of lime, and the solution is again filtered. Sulphuretted hydrogen is then passed through the solution to separate the copper and arsenic present, and the solution is again filtered. After this the whole process is a wet one, in which nothing of an offensive character is or can be given off. The foul slags

from the melting processes are melted with coke in a cupola furnace, a form of cold-blast furnace. A matte separates, which is tapped off from the well at the bottom of the furnace. During melting and the tapping of the slag, arsenical fumes, recognisable by their alliaceous odour, may be freely given off. (Dr. Ballard.)

At the works of Wiggin & Co., nickel refiners, Birmingham, the speiss is roasted in reverberatory furnaces, where the arsenic is driven off as arsenious acid, and condensed in coke scrubbers. The calcined ore is treated with hydrochloric acid in earthenware pans, and the mixed solution is ladled into wooden vats, where it is diluted, and treated with lime chloride sufficient to form sesquioxide of all the iron present, which is then thrown down by adding milk of lime, and carries some of the arsenic with it. The residue left in the earthenware pans is subjected to repeated calcinations and lixiviations till it contains no more nickel. The precipitate formed in the wooden vats is well washed on a flannel filter. The portion remaining behind is sufficiently arsenical to serve for subsequent smelting purposes; the solution is treated with sulphuretted hydrogen to precipitate the bismuth, copper, and lead as sulphides; then with lime chloride at a higher temperature to throw down the cobalt as sesquioxide, and finally with milk of lime to give hydrated oxide of nickel.

The New Caledonian and other non-arsenical ores, are first fused with iron pyrites to get the nickel as sulphide. The mixed sulphides are subjected to a series of calcinations and smeltings to remove the iron and sulphur, after the manner of the copper smelting-process used at Swansea. The nickel oxide obtained is reduced as already described.

Galbraith makes some objections to the existing methods, and indicates improvements. The success in treating the mixed sulphides of nickel and iron with dilute hydrochloric acid depends on the circumstances under which the precipitation takes place; and in precipitating with sulphuretted hydrogen, it is impossible to dissolve all the iron without also dissolving some of the nickel. He overcomes the difficulty by using calcium sulphide as the precipitant; by this means, especially if the solution is hot, the nickel is thrown down as a dense flaky precipitate of sulphide, which dissolves only with difficulty in strong hydrochloric acid, and is almost completely insoluble in a mixture of 1 part concentrated acid to 4 of water. On this he has based a patent for extracting nickel from its ores. The New Caledonian ore is dissolved in acid (hydrochloric or sulphuric), the solution is neutralized with lime-water, and the yellow liquor from "tank waste," or a solution of waste gas lime, is used as the precipitant, being less expensive than the sulphide prepared by boiling sulphur in a thin lime paste. Any iron, magnesia, &c., present in the ore is precipitated, and quite easily separated, without dissolving any of the nickel, by means of dilute hydrochloric acid. (*Jl. Soc. Chem. Ind.*)

Garnier's dry method for New Caledonian ores.—This is analogous to the process followed in the metallurgy of iron: carbon is selected as the reducing agent, and as a vehicle for the nickel and cobalt, instead of the sulphur or arsenic usually employed. The intermediate product is therefore a more or less complex carbide of iron and nickel. The treatment resolves itself into 2 operations:—

(1) Fusion of the Ore to make Nickel Pig.—This is effected by mixing the ore and suitable fluxes with charcoal, which is, however, performed in 2 ways, according as the ore treated is poor in nickel and in iron, or rich in nickel and poor in iron.

In the former case, corresponding to a richness of about 3 per cent. of nickel, there is reason to fear, from the relatively small proportion of the metal, a considerable loss; this is avoided by adding some rich iron ore to the bed of the furnace, so that the total metal may amount to 15 per cent. of the weight of the mass. This process is well adapted

to ores having approximately the following composition :—

Water	21·25	
Silica	41·75	
Nickel oxide . . .	3·50 = nickel	2·75
Iron protoxide . .	5·18 = iron .	4·03
Magnesia	26·65	
Lime	2·20	

Ordinarily, with selected dressed ore, the composition will more nearly resemble :—

Water	10·00	
Silica and insoluble	50·00	
Nickel oxide . . .	18·50 = nickel	14·62
Iron peroxide . .	3·50 = iron .	2·45
Magnesia	15·75	
Lime	2·65	

In this second case, the preceding operation is not called for ; sometimes even only a portion of the iron present is run into the pig with the nickel, which result is easily attained owing to the greater oxidizability of the iron. Part of it then passes into the slag, to which it gives great fluidity, and thus tends to avoid loss by mechanical removal of particles of metal.

The reduction and fusion are conducted in furnaces about 12 ft. high. To avoid complete reduction of the iron, the shaft is made low ; and to prevent too great heat, cold air can be introduced at low pressure. The carbide of nickel and iron obtained may vary from 46½ nickel and 51 iron to 27 nickel and 68 iron, while the carbon fluctuates between 2¼ and 5 per cent.

(2) Refining the Pig.—The pigs whose richness does not permit them to be employed directly in alloys are treated either for nickel, for copper and nickel alloys, or for nickel salts (double sulphate of nickel and ammonia), used in electro-plating. For the last-named the wet method is available, but for the 2 first-named the dry way is required. The operation is conducted on the sole of a furnace resembling that used for making steel. For the commercial alloy of nickel and copper, the charge consists of the nickel and iron carbide with a certain amount of copper. Once these matters are in a state of fusion, the carbon and then the silicon are removed by the oxidizing atmosphere maintained, and finally the iron oxidizes. In order to hasten the operation, sometimes oxidizing agents are added, such as the oxides of copper and manganese. During the process, and especially towards the end, repeated samples are taken to ascertain the progress of the refining, and thus the charge can be run out at the moment when the alloy contains the desired proportions of nickel and copper.

When the object is to produce metallic nickel, the addition of copper is omitted ; the heating is urged, and the oxidizing actions are developed to the utmost ; the carbon and silicon are first eliminated, then comes the turn of the metals, such as chromium, manganese, and iron, which are oxidized and pass into the slag. The nickel remaining, either in the molten state or in lumps, is cast or cut up in marketable quantities.

Christofle's wet way for New Caledonian ores.—The pulverized ore is placed in earthenware vessels and treated with hydrochloric acid, avoiding, by some secret means, complete solution of the magnesia ; a little nitric acid is then added to peroxidize the iron, and the iron and alumina are precipitated by lime chloride or powdered chalk. The lime chloride, in presence of the excess of hydrochloric acid, does not precipitate the nickel. The solution is concentrated, a little oxalic acid is added, and the whole is brought to a boil ; nickel oxalate is precipitated, and requires only to be calcined in a charcoal crucible. If the iron and alumina are precipitated by powdered chalk, lime chloride is added, then a little lime ; black sesquioxide of nickel is deposited, washed, dried, and calcined with charcoal in a charcoal crucible. This has the advantage of avoiding the use of oxalic acid, which is a costly article. The nickel obtained by these processes often runs to 97¾ per cent. pure nickel, with about 1¼ of cobalt, and less than ½ each of silica and manganese.

Properties and Uses.—In many respects, nickel bears a close resemblance to iron. It is slightly more fusible, less magnetic, and possesses about the same

ductility, tenacity, and malleability; it is inferior in electrical conductivity, but infinitely superior in the matter of resisting oxidation, ranking on this score between gold and silver. This power of resisting oxidation, coupled with the ordinary physical qualities necessary in metals, is the secret of the great value of nickel in industrial applications, notably for plating other metals, and as an ingredient in alloys. Mèrmet recommends nickel crucibles instead of silver ones for use in chemical manipulations. Nickel is slightly attacked by melted potash, and so is silver itself. Nickel crucibles cost at first much less than those made of silver, and they have the great advantage of melting at a higher temperature. It often happens that inexperienced chemists melt their silver crucibles in heating them over a gas lamp; but such an accident is not to be feared in working with crucibles made of nickel. Nickel stereotypes would have special value for colour printing, because many kinds of coloured ink attack copper (vermilion, for example) and destroy the plates, while their own brilliancy is also affected by the copper-faced type and plates.

Dr. Fleitman, of Iserlohn, Westphalia, Prussia, has improved and cheapened the operation of refining and toughening nickel, and has reduced the liability to the presence of blowholes in castings by adding to the molten charge in the pot, when ready to pour, a very small quantity of magnesium. This is immediately decomposed, magnesia is formed, and graphite is separated. It would seem that the magnesium decomposes the occluded carbonic oxide, or reduces it to a minimum. The magnesium must be added with great care and in small portions, as it unites explosively with the charge. It is stirred in. About 1 oz. of magnesium is sufficient for 60 lb. of nickel; $\frac{3}{4}$ oz. to 54 lb. of metal has been used with success by Wharton. It is to be noted that complete malleability of nickel was obtained at Wharton's works in Camden, U.S., before Fleitman's invention or process, but this last is more rapid and better than the old method. The metal so treated becomes remarkably tough and malleable, and may be rolled into sheets and drawn into wire. Cast plates can be successfully rolled. The cast plates, such as are made for anodes, after reheating, are rolled down to the desired thickness. It is found that it is a great improvement to the nickel anode plates to roll them down. They dissolve with greater uniformity in the bath. Nickel so treated with magnesium has been rolled into sheets as thin as paper.

Pure nickel, after melting and casting, generally holds a greater or less quantity of oxygen in solution, and the metal is brittle. To hinder the injurious effects of the oxygen, it is necessary to incorporate in the melted nickel some substance which has a strong affinity for oxygen and also for the nickel itself. Garnier finds that phosphorus serves both these purposes very satisfactorily, producing effects analogous to those of carbon in iron. If the phosphorus does not exceed $\frac{3}{10}$ per cent., the nickel is soft and very malleable; above this quantity, the hardness increases at the expense of the malleability. Phosphorized nickel, when alloyed with copper, zinc, or iron, gives results which are far superior to those that are obtained from the same nickel when not phosphorized. By means of the phosphorus, Garnier has been able to alloy nickel and iron in all proportions, and always to obtain soft and malleable products. Nickel welds and melts at the same temperature as steel, and its elongation in forging and rolling is equal to that of Bessemer steel of medium hardness. Nickel-coated sheets of any practical thickness may be got by welding a steel ingot between two nickel ones and passing through a pair of rollers. In the same way nickel-coated steel wire can be obtained by drawing.

Alfred Smeaton Johnstone, of the firm of Wiggin and Co., who had previously been experimenting with manganese, has succeeded perfectly in rendering both nickel and cobalt malleable by means

of manganese. Commercial manganese (about 95 per cent.) or any ferro-manganese may be used for the purpose, the presence of iron not destroying the malleability. Thus the analogy between the treatment of nickel and cobalt and of iron which has undergone fusion is perfect. The manganese is added a little at a time to the fused nickel, which is kept well stirred during the time, and finally poured out into moulds when tranquil. The metal is considerably agitated by the escape of gas during the addition of the manganese. For most purposes, the addition of 2 per cent. of metallic manganese is sufficient; but when the maximum degree of malleability and ductility is required, the quantity added may be increased to as much as 5 per cent., beyond which there is no gain under ordinary circumstances. The manganese left in the nickel need not exceed about $\frac{2}{10}$ per cent. Zinc can be successfully alloyed with nickel by reducing their oxides in a state of admixture. By rapidly fusing the alloy thus obtained, a tough malleable and ductile metal can be made. The melting-point of nickel is too high to admit of zinc being introduced into it after the nickel is molten. The addition of $\frac{1}{10}$ per cent. of magnesium is said to improve the working properties of this alloy. It is not likely that important applications will be long wanting for a metal possessing such valuable properties as malleable nickel, the price (about 4s. a lb.) being comparatively low. Malleable nickel anodes are already being substituted for the old cast anodes. The former certainly have a great advantage in their uniformity of structure, which not only prevents to a great extent their being eaten away irregularly, but also avoids loss through secondary currents. (Prof. Huntington, *Jl. Soc. Chem. Ind.*)

See also under "Alloys," pp. 20, 22, 25, 35, 41.

NIOBIUM.—This rare metal usually occurs with tantalum, in the form of an oxide (Nb_2O_5), in the following uncommon minerals:—51½ to 78 per cent. in columbite, 47 to 51 per cent. in pyrochlore, 45 per cent. in fergusonite, 42 per cent. in yttrotantalite, 35 per cent. in euxenite, and 7½ to 29 per cent. in tantalite. Roscoe has obtained the impure metal (containing small quantities of hydrogen, and chloride and oxide) as a steel-grey crust by repeatedly passing the vapour of the pure chloride with hydrogen through a red-hot tube, which was then more strongly heated in a porcelain tube traversed by hydrogen. Niobium is dissolved by concentrated sulphuric acid, being scarcely affected by even heated nitric or hydrochloric acids or aqua-regia; it ignites and oxidizes with vivid incandescence on heating in the air at a low temperature.

OSMIUM.—This metal is met with chiefly in the natural alloy osmiridium, in proportions varying from 27¼ to 43½ per cent., as well as in minor quantities in platiniferous minerals. It is obtained in the form of a more or less pure and very volatile tetroxide in the course of preparing the other members of the platinum group by the following process of Deville et Debray:—The osmiridium ore is fused with zinc. the regulus is treated with hydrochloric acid, the finely divided residue is mixed with the same quantity of barium nitrate and 3 times the quantity of barium binoxide, and the mass is heated for 2 hours at about 1800° F. (982° C.); the resulting compound is cooled, ground very fine, and put into a stoppered vessel containing dilute hydrochloric acid, which must be kept cool and placed in a thorough draught, to prevent the poisonous osmium tetroxide vapours escaping. On completion of the reaction, 2 parts sulphuric and 1 of nitric acid are added, the mixture is well shaken, the barium sulphate is allowed to deposit, and the clear liquid is poured off; the residue is washed by decantation, and ¾ of the liquid are distilled over; this distillate is precipitated by ammonia and ammonium sulphide, and the precipitate is mixed with sodium chloride, and heated in a slow current of chlorine; the lixiviated mass gives

sodium osmichloride solution, from which sal-ammoniac precipitates ammonium osmichloride, and this, washed with sal-ammoniac solution and heated in a covered crucible, yields spongy osmium. Deville et Debray also obtain pure osmium in the form of an amorphous powder by passing the vapour of the pure tetroxide, mixed with carbon monoxide and dioxide, through a red-hot porcelain tube. Crystalline osmium may be produced by fusing the powder with 3 or 4 times its weight of tin in a charcoal crucible, treating the alloy with acid, and heating the residue in a current of hydrochloric acid gas. Metallic osmium has a sp. gr. of 22·477; it is infusible, but evaporates at the temperature reached when iridium is fully melted, and deposits as a black powder on cold surfaces introduced into the vapour. Its alloy, osmiridium, is used for tipping gold pens and for compass bearings, being inoxidizable, proof against acids, and not magnetic.

PALLADIUM.—This valuable metal occurs in most platinum ores and in alloy with gold. It may be separated from other platinum metals by taking advantage of the fact that, in neutral solutions, mercuric cyanide gives an insoluble precipitate of palladium dicyanide. In preparing pure palladium from the platinum residues of the St. Petersburg mint, Bunsen adds potassium iodide to a solution of palladium dichloride, when palladium di-iodide separates out as a black insoluble precipitate. For preparing the commercial metal on the large scale from the residues of platinum works, the following process is most convenient:—

Philipp describes the following method for recovering the palladium, rhodium, ruthenium, osmium, and iridium contained in the mother-liquors of the platinum manufacture. These liquors are boiled down, by which iridium chloride separates out with a little platinum. The concentrated liquor is stood aside for a time, poured off from the deposit of iridium, diluted, and precipitated by zinc. The precipitate is digested with hydrochloric acid, washed, and ignited. Aqua-regia dissolves the palladium and a little gold, while impure rhodium remains behind. The solution is supersaturated with ammonia, and the palladium is precipitated by hydrochloric acid. The residue from the platinum solutions, which in Russian platinum averages 8 per cent., is ignited, ground, and washed, to remove the greater part of the iron, &c. The pulp, now amounting to 2 or 3 per cent. of the original material, is smelted with an equal quantity of a mixture of borax and nitre till the mass flows smoothly. After treating with hydrochloric acid and water, the metals remain behind. They are alloyed with twice their bulk of zinc in a graphite crucible; the alloy is broken up and powdered, and freed from zinc by adding hydrochloric acid. The residue is treated with chlorine in a Hessian tube, and iridium and osmium chlorides, with a little platinum, are thus obtained. The remaining mass is ignited in a current of hydrogen, and smelted with caustic potash and nitre to afford its ruthenium.

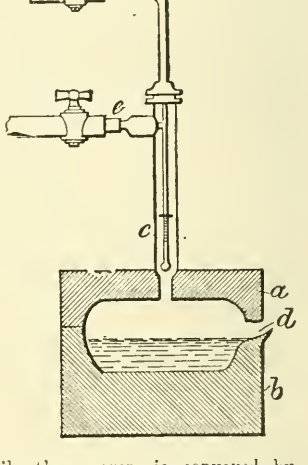
Commercial palladium may be purified by Bunsen's process, already described, or in the following manner:—To a solution of the impure metal, as free from acid as possible, ammonia is added till the precipitate formed re-dissolves; hydrochloric acid gas is then passed into the solution, and throws down palladio-ammonium chloride, leaving copper and iron in solution; the precipitate, washed and ignited, yields spongy palladium. The same result is attained by igniting palladium cyanide. Metallic palladium is rapidly dissolved in hot nitric acid, especially when nitrous acid, copper, or silver is present; the spongy metal dissolves in hydrochloric acid in contact with the air, and the compact when chlorine is passed in; also in boiling concentrated sulphuric acid, and in fused potash bisulphate; it has a sp. gr. of 11·4, a silvery colour, and a fusing-point about equal to that of wrought iron; its colour and appearance are unalterable by exposure to the air or to sulphuretted hydrogen. It has been chiefly used as a substitute for

gold in dentistry, and for graduated surfaces on scientific instruments.

PLATINUM.—This metal occurs almost exclusively in the native state, but is seldom pure. Analyses of samples from Australia, California, the United States of Colombia, and the Urals, show 61½ to 86¼ per cent. of the metal, combined with varying proportions of copper (½ to 4), gold (½ to 1¼), iridium (¾ to 4¼), iron (4½ to 11¾), osmiridium (½ to 26), palladium (½ to 1¾), and rhodium (¼ to 1¾). The preparation of the malleable metal from the raw material is generally effected in the wet way. As first conducted, this was as follows:—The crude mineral is dissolved in 15 times its weight of aqua-regia (equal parts of nitric and hydrochloric acids), and precipitated by sal-ammoniac; this precipitate of platin-ammonium chloride is dried, pressed into a conical fire-clay mould, and ignited; thus the platinum is obtained as a coherent mass. The ultimate ductility of the product is found to depend upon gently heating the double chloride at a temperature just sufficient to expel all the sal-ammoniac, and occasion the least possible cohesion of the platinum particles. This metallic powder is rubbed in the hands till it will pass through a fine lawn sieve, then well levigated, and the cold pulp filled into a conical brass barrel, and pressed very hard; the hardened cake is removed, heated to redness on a charcoal fire to expel moisture and increase the cohesion, then subjected to about 20 minutes' ignition in the highest attainable heat of a blast furnace, and, while still hot, placed on an anvil and hit with a heavy hammer, when the ingot of metal can be applied to the usual purposes where ductility is required. This process is still very commonly adopted, in spite of its tediousness.

Several dry methods have been introduced with more or less success. The first step in this direction was the application of the oxy-hydrogen blowpipe to the fusion of large masses of platinum. The arrangement mostly employed is shown in Fig. 157; it consists of 2 well-fitting lumps of quicklime *a b*, the upper one *a* having a hole drilled in the centre for the insertion of the blowpipe *c*, while a side opening *d* serves as an exit for the products of combustion and for the molten metal. The hydrogen or common coal-gas (the latter being more generally used) enters by the tube *e*,

FIG. 157.



while the oxygen is conveyed by *f*, meeting in the blowpipe *c*, whose upper part is of copper and lower part of platinum. The lime crucible well withstands a high temperature, and absorbs the slags of the iron and silicon oxides and other matters formed during the fusion. Based upon this principle Deville et Debray have proposed 2 dry ways of treating platinum minerals, as follows:—(*a*) The ore, mixed with lime, is merely fused, when a platinum-iridium-rhodium alloy is produced; this is well adapted for melting down old platinum vessels, as the impurities (gold, iron, lead, phosphorus, sulphur) are either volatilized or absorbed by the lime. (*b*) This takes advantage of the fact that lead alloys with platinum but not with osmiridium; the platinum ore

is mixed with galena, and some glass and borax as fluxes, and treated in an ordinary melting crucible; the osmiridium goes to the bottom, and litharge is gradually added till no more sulphur dioxide is evolved; when the mass is cool, the lead alloy at the top is removed and cupelled, and the platinum residue (containing a little iridium and rhodium) is fused in a lime crucible by the oxy-hydrogen flame. But it is difficult to ensure by these means that the platinum obtained is either homogeneous or free from foreign matters.

Heräus, at Hanau, Germany, employs the following, process:—The raw ore is dissolved in a mixture of 1 part aqua-regia and 2 of water in a glass retort under a pressure of 12 in. of water (Dullo having shown that the solution of platinum is facilitated by pressure); the solution is evaporated down, and the dried mass is heated to 257° F. (125° C.), when the palladium and iridium salts are reduced to chlorides. From the clear solution, acidified by hydrochloric acid, pure platinum chloride is precipitated by adding sal-ammoniac, whilst iridium chloride is recovered by evaporating down the mother-liquor. The solution remaining after precipitation of the platinum chloride is treated with scrap-iron, and the precipitate, freed from excess of iron by adding hydrochloric acid, is re-dissolved in aqua-regia; from this solution, further quantities of platinum and iridium chlorides are thrown down by sal-ammoniac. From the mother-liquors, and from the residue left on dissolving the ore in aqua-regia, palladium, rhodium, ruthenium, osmium, and iridium are obtained. The platinum sponge produced by igniting the chloride is compressed, broken up, and fused into a mass by heating in an excess of oxygen in a lime crucible.

Commercial platinum is rarely pure, containing generally a considerable proportion (about 2 per cent.) of iridium, and a little rhodium, with sometimes other bodies. Johnson and Matthey prepare pure platinum in the following manner:—The ordinary commercial platinum is melted with 6 times its weight of pure lead; the mass is granulated, and slowly dissolved in dilute nitric acid (1 vol. acid to 8 water), being placed for this purpose in porcelain baskets, such as are used for holding the manganese oxide when making chlorine. When the first charge of acid is sufficiently saturated, a fresh quantity should be added till no more action is apparent; at this stage, the greater part of the lead will have been dissolved out, together with a portion of any copper, iron, palladium, or rhodium that may have been present. These metals are subsequently extracted from the mother-liquors, the lead nitrate by crystallization, and the others by well-known means. The residue is an amorphous black powder, consisting of platinum, lead, and small portions of other metals originally present, the iridium existing as a brilliant crystalline substance insoluble in nitric acid. After digesting this compound in weak aqua-regia, immediate solution of the platinum and lead takes place, leaving the iridium still impure, but effecting complete separation of the platinum. To the platinum and lead chlorides, after evaporation, is added sufficient sulphuric acid to effect the precipitation of the whole of the lead as sulphate; and the platinum chloride, after solution in distilled water, is treated with excess of ammonium-sodium chloride, the excess being to ensure that the precipitated yellow double salt may remain in a saturated solution of the precipitant. The whole is then heated to about 176° F. (80° C.), and allowed to stand for some days; the ammoniochloride of platinum settles down as a firm deposit at the bottom of the vessel, whilst any rhodium present will colour the surface liquor a rose tint by combination of the salts of the 2 metals. The precipitate is repeatedly washed with saturated solution of ammonium chloride, and subsequently with distilled water charged with pure hydrochloric acid. The small quantity of the double salt taken up and held in solution is recovered afterwards. Rhodium may

still exist in the washed precipitate, which must therefore not be reduced to the metallic state until its separation is completed; this is best effected by mixing with the dried compound salts of ammonia chloro-platinate and chloro-rhodiate, potash-bisulphate and a small proportion of ammonia bisulphate, and subjecting to a gradual heat, brought by degrees up to a dull-red, in a platinum capsule, over which is placed an inverted glass funnel. The platinum is thus slowly reduced to a black, spongy, porous condition, free from water, nitrogen, ammonia sulphate, and hydrochloric acid, the rhodium remaining in a soluble state as rhodium bisulphate and potash, which can be dissolved out completely by digesting in boiling distilled water; a small quantity of platinum will have been taken up in a state of sulphate, but is regained by heating the residue (obtained on evaporation) to redness, at which heat it is reduced to the metallic condition, the rhodium salt remaining undecomposed. The resulting platinum is absolutely pure.

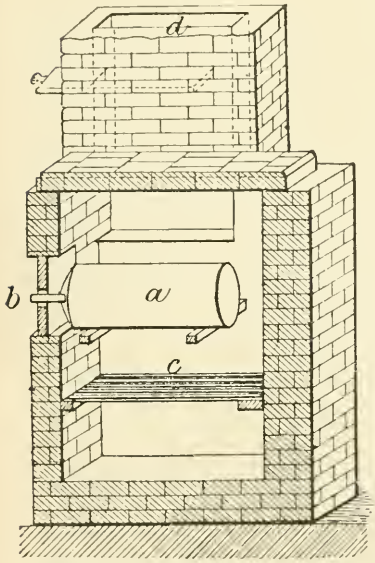
Deville et Debray prepare pure platinum on the large scale by the following process:—The crude metal, containing iridium and rhodium, is fused with 6 to 10 times its weight of pure lead (obtained by calcining pure lead acetate); the cooled mass is treated with nitric acid, and the residue with dilute aqua-regia, when a crystalline alloy of iridium, ruthenium, and iron forms, and remains behind, while the lead, platinum, and rhodium (partially) are dissolved. [If the platinum is rich in rhodium, this is not dissolved by the aqua-regia, but will be separated from the iridium-ruthenium-iron alloy by concentrated boiling sulphuric acid.] The lead-platinum solution is treated with sal-ammoniac, when the double chloride of ammonium and platinum is precipitated, leaving the rhodium in solution. The precipitate is washed in water soured with hydrochloric acid, and ignited; the resulting metal is heated in a lime crucible till fusion is complete, when the heating is abruptly stopped, so that solidification proceeds from without, and thus avoids the formation of bubbles.

Properties and Uses.—Platinum possesses properties which render it practically indispensable in chemical and metallurgical pursuits. It is inoxidizable at any temperature by oxygen, water, or sulphuric or nitric acids; but it is attacked by aqua-regia, by sulphur in presence of alkalies, by alkalies themselves, by nitre, and by alkaline cyanides; the silicon reduced from the ash of burning charcoal combines with the metal, rendering it brittle and liable to crack; the heating of platinum vessels in a flame where the combustion is incomplete causes formation of platinum carbide, which oxidizes, and produces blisters; arsenic and phosphorus alloy with platinum when heated in contact, as also do the easily-reducible metals at a high temperature. The commercial platinum, containing about 2 per cent. of iridium as an impurity, is better than the pure metal for making chemical apparatus, as it withstands acids in a superior degree; new platinum crucibles may be tested by boiling in hydrochloric acid and then in pure nitric acid, when none of the metal should be dissolved; the cleansing of crucibles is best effected by fusing potash bisulphate in them. Pure platinum has a sp. gr. of 21·5, a tin-like colour, the softness of copper, and malleability ranking next to gold and silver; it welds readily at a white heat, but is infusible in mass, even in the highest heat of the blast furnace, succumbing only to the oxy-hydrogen flame; this latter is now utilized for joining platinum seams by autogenous soldering, instead of using gold as was formerly the case. In the forms known as "spongy platinum" and "platinum black," the metal is much used as an oxidizing agent. The preparation of the former has already been described; the latter is best obtained by warming a solution of platinum bichloride in potash with alcohol.

POTASSIUM.—Salts of potassium (silicates and chlorides mainly)

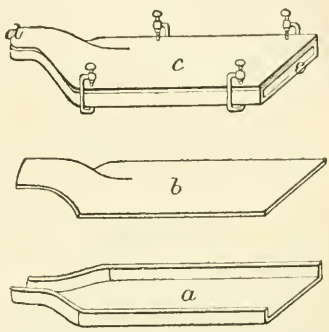
exist in several rocks, and in most soils and mineral waters. The metal is prepared from the carbonate by reduction with carbon at a white heat. Acid potassium tartrate (crude tartar) is ignited in a covered iron crucible, and the porous charred mass is rapidly cooled by dipping the crucible into cold water, and then transferred to a retort. This latter was until lately represented by a wrought-iron mercury-bottle, but malleable-iron tubes covered with a coating of fire-clay are now substituted. The arrangement of the retort and furnace is shown in Fig. 158. At a white

Fig. 158.



heat, the reduction takes place, a mixed vapour of metallic potassium and carbon monoxide being generated. At a very high temperature these vapours combine to form a very explosive black substance, represented by the formula $K_2C_2O_2$, rendering the process one of great danger. The risk of explosions may, however, be avoided by employing the condenser introduced by Mareska and Donny, and shown in Fig. 159, which effects very rapid cooling of the vapours before the explosive combination can take place. This condenser consists of

Fig. 159.



a tray *a* and cover *b* of cast iron, which can be clamped together as in *c*, so as to form a shallow box almost $\frac{1}{4}$ in. deep, 10 to 12 in. long, and 4 to 5 in. wide; the socket at *d* fits in the short tube emerging from the end of the retort or bottle, while the other end *e* is left open to give free passage to the vapours. When these latter commence to appear at the exit tube of the retort, the condenser is attached, and the metal begins to condense into a liquid state, and flow into a vessel containing petroleum, placed below to receive it; any deposit obstructing the exit tube must be promptly removed by inserting a red-hot rod.

On the small scale, metallic potassium can be prepared by electrolysing the cyanide or the chloride. In the former case, the salt is melted and allowed to cool so as to form a solid crust, when a current from 3 or 4 Bunsen cells is passed through by means of gas-retort carbon poles. In the second case, a mixture of potassium and calcium chlorides, in equal molecular proportions, is fused in a small porcelain crucible over a lamp, with carbon poles from 6 or 8 Bunsen couples dipping into the fused salt; the lamp-flame is adjusted so that the portion of salt

around the negative pole may solidify, while that around the positive pole remains fluid, thus allowing the free escape of the chlorine; the current is passed for about 20 minutes, when the crucible is allowed to cool, and is opened under petroleum, affording a deposit of pure potassium around the negative pole.

The metal possesses some singular physical and chemical properties. While brittle and of crystalline fracture at 32° F. (0° C.), it softens like wax at 59½° F. (15° C.), and can easily be cut by a knife, the clean surfaces being readily welded again; it melts at 144½° F. (62½° C.), and boils at a red heat; it has a silvery lustrous appearance, and a sp. gr. of 0·875 at 55½° F. (13° C.); it dissolves in liquid ammonia, and is re-precipitated unchanged on evaporation of the solvent; in ordinary atmospheres, its surface is converted into caustic potash and carbonate, oxidation often proceeding so rapidly when the metal is in thin shreds that ignition ensues, and the metal burns, but in quite dry pure air it undergoes no change; in electro-positiveness it ranks next to cæsium and rubidium; it decomposes water so energetically that sufficient heat is developed to ignite the hydrogen evolved; and its powerful reducing properties give it a use in chemical operations, where, however, it is generally replaced by its cheaper ally sodium.

RHODIUM.—This member of the platinum group of metals is prepared from the solution remaining after throwing down ammonio-platinum chloride, by precipitating by metallic iron, and fusing the deposit with 1 part lead and 2 parts litharge to form a regulus; the copper, lead, and palladium are dissolved out by dilute nitric acid, and the insoluble residue is mixed with 5 parts barium binoxide, and heated to redness for 2 hours; the mass is lixiviated with water, and the residue is boiled with aqua-regia to volatilize the osmium tetroxide, which is condensed (see p. 400); the barium in excess is precipitated by adding sulphuric acid, and the filtrate is evaporated at 212° F. (100° C.) with excess of sal-ammoniac; the residue is washed with sal-ammoniac solution so long as a rose-red colour is communicated to the wash-water, and the filtrate is evaporated with nitric acid in excess to decompose the sal-ammoniac; the solid residue is heated to redness with 3 or 4 parts of sulphur, and rapidly boiled out with aqua-regia and sulphuric acid. The resulting nearly pure metallic rhodium may be refined by fusing with 3 or 4 parts of zinc, and treating the alloy with strong hydrochloric acid; it is then dissolved in aqua-regia, and evaporated with ammonia in excess; the rhodium-ammonium chloride which separates out is purified by re-crystallization, ignited with sulphur in a graphite crucible, and finally fused in an oxyhydrogen furnace to remove traces of osmium and silicon. The pure metal is less fusible than platinum, has a sp. gr. of 12·1, and resembles aluminium in lustre and colour; it is almost insoluble in all acids, though its alloys dissolve in aqua-regia; it is attacked by chlorine more readily than any other member of the platinum group, and can be dissolved by repeated ignition with phosphoric acid, acid phosphates, or fused potash bisulphate.

RUBIDIUM.—This comparatively newly-discovered metal is widely distributed in minute quantities in the minerals containing other alkali metals, such as lepidolite (0·24 per cent. of rubidium oxide), carnallite, and mica, as well as in sea-water, brine springs, and mineral waters, and in many plants and the potashes made from them. The best material to work upon for the preparation of the metal is the saline residue left in procuring lithium from lepidolite (see p. 363), containing sodium, potassium, lithium, and traces of rubidium and cæsium, all in the form of chlorides. About 2¼ lb. of this residue is dissolved in 5½ lb. water, and the cold solution is precipitated by adding a solution of 30 *grm.* platinum in aqua-regia; when the precipitate has settled, it is collected and boiled 25 times with

successive small quantities of water, in each case poured upon the original solution, and amounting in all to about 3½ lb.; thus is formed a fresh precipitate, which is again washed and treated as the first; this series of operations is repeated 7 or 8 times, till nearly all the rubidium is exhausted, when each platinum precipitate is dried, the platinum is reduced by hydrogen, and the alkaline mass is dissolved in water, giving about 125 *grm.* rubidium chloride, with 3 or 4 per cent. potassium chloride and a little cæsium chloride; the potassic impurity can be almost completely removed by repeating the precipitation and washing. The metal itself is best prepared by the same process as that used for potassium (p. 405), charred rubidium tartrate being heated to whiteness in an iron tube, and yielding about 5 oz. of the metal from 75 oz. of the tartrate. The metal has a silver-white colour, and a sp. gr. of 1·52; it is soft and wax-like at 14° F. (−10° C.), and melts at 101½° F. (38½° C.); on exposure to the air, it is immediately coated with a bluish suboxide, and ignites even more readily than potassium.

RUTHENIUM.—This member of the platinum group of metals occurs in osmiridium (½ to 6½ per cent.) and platinum "ores," and as sulphide in laurite. It is best prepared by Deville et Debray's method from the osmiridium-ruthenium alloy. This latter is fused with zinc, and the regulus thus obtained is treated with hydrochloric acid; 1 part of the residue in a finely-comminuted state is mixed with 3 of barium binoxide and 1 of barium nitrate, and the mixture is heated for 2 hours to a temperature somewhat below the melting-point of silver; when cold, the solid mass is reduced to impalpable powder, and added to hydrochloric acid contained in a stoppered vessel, which is kept quite cold to prevent liberation of osmium tetroxide vapour, the operation being conducted where the ventilation is efficient, on account of the poisonous nature of this vapour; when all action has ceased, 1 part nitric and 2 parts sulphuric acid are added, the mixture is shaken, the barium sulphate deposit is allowed to settle, the clear liquid is poured off, and the residue is washed by decantation; the liquid is distilled till ¾ have passed over, and the distillate is treated for recovery of osmium (see p. 400); the concentrated residue, mixed with 2 or 3 parts sal-ammoniac and a little nitric acid, is dried in a water-bath, and washed with water half saturated with sal-ammoniac till the filtrate is colourless, thus leaving behind an ammonium-iridichloride containing some ruthenium; on igniting this, it affords a spongy metallic mass, which is fused for 2 hours in a silver basin with 2 parts nitre and 1 of caustic potash, then dissolved in water (forming potassium ruthenate), and treated with nitric acid till the yellow colour disappears, when ruthenium oxide, contaminated with silicic acid, iridium, and osmium, separates out; this is ignited in a graphite crucible and fused in the oxyhydrogen furnace. To obtain the metal chemically pure, it is heated in a current of oxygen till all the osmium tetroxide has been volatilized, then refused with nitre and caustic potash, dissolved in water, saturated with chlorine, and distilled in a stream of chlorine in a water-bath; the pure ruthenium tetroxide volatilizes; this is dissolved in caustic potash, and the sesquioxide is precipitated by alcohol, and again reduced to the metallic state by ignition in a stream of coal-gas or hydrogen. The fused metal oxidizes slowly in the air, taking on a brown film; the pure metal is almost unattacked even by aqua-regia, but combines with chlorine at a red heat; it is hard, brittle, almost as difficult to fuse as osmium, and has a sp. gr. of 12·261 at 32° F. (0° C.).

SELENIUM. — This element, which fills an intermediate place between tellurium and sulphur, occurs mainly in connection with the latter body, being found in association with native sulphur itself, and with the sulphides of iron, copper, lead, and molybdenum, as well as with tellurium ores and pitchblende (uranium ore). The commercial sources of selenium

are three-fold:—(*a*) the native double copper-lead selenide found in the Hartz; (*b*) the deposits formed in sulphuric acid chambers and flues where seleniferous brimstone or pyrites is burned; (*c*) the fine-dust of roasting furnaces in works where lead desilverization is carried on. Following are the processes of extraction employed.

(*a*) The pulverized copper-lead selenide is treated with hydrochloric acid to dissolve the earthy carbonates; the residue is washed, dried, and ignited for some time with an equal quantity of black flux; by this means, the selenium is converted into potassium selenide, which is dissolved away by boiling water from the oxides simultaneously formed; the solution undergoes oxidation on exposure to the air, and a grey deposit of selenium results; this is washed, dried, and distilled.

(*b*, 1) The seleniferous deposit is mixed with potassium nitrate and carbonate, and deflagrated in a red-hot crucible; the residue, containing potassium selenate, is heated with hydrochloric acid, and the whole is evaporated down to small bulk; a reducing action is thus set up, and selenious acid is liberated; on saturating the solution with sulphurous acid, and heating to boiling, red amorphous flakes of selenium are thrown down.

(*b*, 2) The deposit is treated with aqua-regia; the excess of this acid is expelled by heat after addition of sulphuric acid; the cooled residue is washed with water, the solution is neutralized with sodium carbonate, and the mass is evaporated to dryness; the residue is roasted at a gentle heat with an equal quantity of sal ammoniac till it assumes a reddish-brown colour; the mass is then treated with water, which leaves the selenium undissolved.

(*b*, 3) The deposit is washed, and digested with a moderately strong solution of potassium cyanide at 176° to 212° F. (80° to 100° C.), till the red colour just changes to pure grey; the residue is lixiviated with boiling water till the liquid ceases to assume a reddish opalescent appearance on addition of hydrochloric acid; after filtering the solution, the selenium is precipitated by hydrochloric acid; it contains as impurities small quantities of copper, iron, and perhaps mercury, from all which it may be freed by converting it into selenious oxide, subliming this compound, and precipitating the selenium by sulphurous acid.

(*b*, 4) In order to recover that portion of the selenium which is carried into the sulphuric acid in the chambers, this latter ("chamber acid") is allowed to run down a Glover tower without the addition of any nitrated acid; it is thus brought into contact with the reducing gases from the chambers (the SO_2), which precipitate the selenium encountered as a red amorphous powder; the reddish turbid acid thus obtained is allowed to settle, and decanted, and the deposit of selenium is washed, and dried at 212° F. (100° C.).

(*c*) The flue dust, containing 9 per cent. of uncombined selenium, is levigated, the heavier parts being washed out with water containing hydrochloric acid, and then with pure water; the mass is then fused with crude sodic or potassic carbonate, pulverized and lixiviated; on leaving the brown-red liquid exposed to the air, the selenium deposits; this is separated by filtration, and distilled.

Selenium is insoluble in hot and cold water, very slightly soluble in concentrated sulphuric acid, and is oxidized and dissolved by nitric acid and aqua-regia. In the variety of its modifications of form, it bears a striking resemblance to sulphur. The crystalline form conducts electricity more readily than the vitreous, its capacity in that respect increasing with the temperature.

SILVER. *Occurrence.*—This metal frequently occurs in the native state, sometimes in masses of great weight (5 to 10 cwt.) but more or less contaminated with copper, gold, and mercury. The most common ores are as follows:—(1) The sulphide ("silver glance"), a combination of 87 parts silver and 13 sulphur, most abundantly

found in association with the sulphides of the baser metals (lead, copper, antimony, iron, zinc) and arsenic, and recovered by processes incidental to the treatment of the ore for its other constituents; (2) the chloride ("horn silver"), containing 75 parts silver and 25 chlorine; (3) the antimonio-sulphide ("ruby silver"), consisting of 60 parts silver, 22½ antimony, and 17½ sulphur; (4) the cupro-sulphide ("silver-copper glance"), giving 53 parts silver, 31¼ copper, and 15¾ sulphur; (5) the arseno-sulphide ("light-red silver"), composed of 65½ parts silver, 19½ sulphur, and 15 arsenic; (6) "antimonial silver," yielding 78 parts silver, and 22 antimony; and (7) the cupro-antimonio-arsenical sulphide, affording about 95 per cent. silver. The German "buttermilk ore" is a mixture of silver chloride and clay.

Extraction.—The processes designed for the preparation of metallic silver from the minerals with which it is associated, may be catalogued in 3 groups, that being the number of distinct principles involved. According to the first, it is amalgamated with mercury, and the latter is then distilled off: this constitutes the "amalgamation" system. Or it may be alloyed with lead and recovered by subsequent oxidation of the lead: the "cupellation" process, which sometimes entails a preliminary step known as "eliquation." Or it may be converted into a salt, and brought into solution, and then be re-precipitated in the metallic form by means of copper: such processes are collectively denominated "wet methods."

(*a*) Amalgamation. (1) Patio process.—The earliest and rudest of the amalgamation methods is that known as the Mexican or *patio* process, which is employed in the treatment of ores containing metallic silver, sulphide, and chloride, disseminated through large masses of worthless material, situated in a locality devoid of both cheap fuel and plentiful water. The first step is the reduction of the ore to a more or less fine pulp, by a process of grinding in an *arrastra*, the ore being previously smashed into pieces of pretty uniform size in a set of perpendicular dry stampers. The *arrastra* or *tahona*, where the fine grinding with water is performed, consists of a circular inclosure of stone paving about 12 ft. across, surrounded by a wall about 2 ft. high, and provided in the centre with a post fixed in a footstep below, and in a beam above, and having attached to it a series of arms, from which depend heavy blocks of stone; these arms are made to revolve by mules harnessed to the outer end, and the ore is ground by being placed between the stone paving and circulating blocks, the latter being made of porphyry, granite, or basalt, and measuring some 16 in. thick, by a length that just allows them to revolve clear of the wall at one side and the centre post at the other. The charging of the *arrastra* is performed somewhat differently according to local peculiarities of the mineral treated. When the ore contains gold and is reduced to a very fine state, some 600 to 1100 lb. of the coarse "sand" (*granza*) from the stampers are introduced with 10 gal. water at 4 A.M.; this is supplemented by the addition of 10 gal. more water at 9, 10 gal. more at 12, 30 gal. more at 3 P.M., and 50 gal. more at 4, and the grinding is continued for another 12 hours. In the meantime, small quantities of mercury, or silver-amalgam, or copper-amalgam, are repeatedly thrown into the *arrastra*, with the object of collecting any gold that may be present; this lies undisturbed for periods of 3 to 6 months in the bottom of the *arrastra*, and is removed at such intervals to be strained, retorted, and run into bars. After 24 hours' total grinding, the mud or "pulp" (*lama*) is either baled out or tapped into barrels for removal to stone tanks (*lameros*) where a portion of the water may evaporate in the sunlight and leave a paste fit for the *patio*. Ores containing no gold require a less degree of comminution.

The *patio* or amalgamation floor is a stone-paved area of some 250 to 300 sq. ft., rendered smooth and water-tight

by cement, and slightly inclined to facilitate drainage. A heap (*torta*) of the pulp is conveyed from the *lameros* to a circular patch 30 to 50 ft. wide on the *patio*, amounting perhaps to nearly 100 tons, and forming a deposit about 1 ft. thick, retained by a temporary stone or plank wall with well-pugged joints. As soon as, by evaporation of the water, it has arrived at the consistence of thinnish mud, 3 to 5 per cent. of common salt is added, and the *torta* is stirred up by wooden shovels, and well trodden (*repaso*) by mules turned in for the purpose, which are blindfolded, yoked in fours, and guided by a driver in the centre, who causes them to gradually diminish the radius of the circle described. The salt is left to exercise its influence during the night, and the next day the mass is treated with mercury and a material termed *magistral*. This latter is prepared by slowly roasting a mixture of iron- and copper-pyrites with a little salt in a reverberatory furnace, resulting in the formation of cupric and ferrous sulphates with some chlorides; the cupric sulphate, constituting 20 to 40 per cent. of the mass, is the most important ingredient, and its proportion regulates the amount of the *magistral* to be used, but the 6 to 12 per cent. of iron salt is not without some value. The *torta* being in a fit condition (or rendered so by adding water if necessary), about 1 per cent. of its bulk of *magistral* is spread evenly over its surface from wooden shovels, and the mass is trodden for 1 hour; next the mercury is introduced by squeezing it through canvas so as to break it up into fine particles, the proportion being generally 3½ to 4 lb. for every every *marco* (say ½ lb.) of silver estimated to be present, and the treading operation is repeated. Chemical action soon commences in the mass, and its progress is watched by the periodical examination of ½-lb. samples taken from all parts. These are washed with water in a little bowl, by which the earthy particles are carried away, and the metallic portion is exposed to view. If the mercury exists in tiny globules without having undergone much change of colour, the *magistral* is in insufficient quantity; but if it presents a leaden aspect, there is an excess of *magistral*, and a small dose of lime may be required, to limit the action on the mercury; while a light-grey appearance is indicative of good working order, and the globules in the sample taken next day will show a whitish hue and assume a scaly form on pressure, being largely impregnated with silver. The samples are generally taken 3 times daily, viz: before, during, and after the day's treading, and they must be chosen from all parts of the mass. The treading increases and hastens the action of the *magistral*, and is usually completed in 15 to 45 days. Towards the end of the operation, the mercury globules on being rubbed show little amalgam, and finally they become almost altogether free from silver, and run together in the bottom of the bowl, when the mass is considered to be exhausted of its silver, and is subjected to a washing process.

Before proceeding to describe the next step, it will be interesting to notice some remarks made by Prof. Huntington (*Jl. Soc. Chem. Ind.*) on the nature of the reactions which take place in the *torta* on the *patio*. The following are some of the main points investigated:—

1. Mercury worked up with silver sulphide, sodium chloride, sand and water, extracted about ⅞ of the silver present, and 3 times as much as when sodium chloride was absent. The presence of iron oxide causes loss of mercury when the mixture contains sodium chloride, owing to ferric chloride being formed, which is reduced to ferrous chloride by the mercury, with formation of calomel. A very little iron oxide has a marked effect, as the ferrous chloride, as fast as formed, re-oxidises, in contact with the air, to ferric chloride, and so on.

2. When, in addition to the sodium chloride, the mixture was made up with copper sulphate, which would produce copper chloride by double decomposi-

tion, rather less silver was obtained, and the loss of mercury was greater. However, on substituting the mineral proustite (silver 65·5, arsenic 15·1, sulphur 19·4) for the artificial silver sulphide, twice as much silver was extracted by the mercury when the mixture contained copper chloride. The decomposition of the silver sulphide is very imperfect, unless the mixture be frequently and thoroughly agitated.

3. Zinc sulphide, in the presence of cupric chloride, causes the formation of copper sulphide and zinc chloride. It is well known that ores containing blende amalgamate badly.

4. A number of experiments were made to establish the action of cupric and cuprous chlorides on silver sulphide. The generally accepted explanation of the action of the copper chloride in the Mexican amalgamation process is embodied in the following equations:—

1. $Ag_2S+2CuCl_2=2AgCl+Cu_2Cl_2+S$;
2. $Ag_2S+Cu_2Cl_2=2AgCl+Cu_2S$.

In the experiments made by Prof. Huntington, it is shown that the liberation of the sulphur is entirely due to a secondary reaction, which takes place only to a limited extent. It may be represented as follows:—

PRIMARY:

$$Ag_2S+CuCl_2=2AgCl+CuS;$$

SECONDARY:

$$CuS+CuCl_2=Cu_2Cl_2+S.$$

The secondary reaction takes place *pari passu* with the primary, at the moment double decomposition is occurring between the cupric chloride and the silver sulphide, and is brought about by the copper of the chloride concerned in the reaction reducing to a lower chloride a further quantity of cupric chloride, in preference to combining with the sulphur of the silver sulphide; so that in the result silver chloride, cuprous chloride, and free sulphur are produced. The experiments, as a whole, lead to the conclusion that the amount of cuprous chloride formed and of sulphur set free is directly dependent on (*a*) the strength and quantity of a solvent for cuprous chloride present, such as NaCl and $CuCl_2$, (*b*) the temperature, (*c*) the presence of air. The secondary reaction is limited by the power of the solution to dissolve cuprous chloride. Obviously, if the cuprous chloride in solution can by any means be removed, the solvent power of the solution will be to a certain extent renovated. The action of air in facilitating the secondary reaction is therefore due to its converting the cuprous chloride into insoluble oxychloride, according to the equation—

$$3Cu_2Cl_2+3H_2O+3O=3CuO.CuCl_2.3H_2O+2CuCl_2.$$

5. In the course of these experiments it was found that when silver sulphide is treated with a strong solution of cupric chloride at a high temperature (boiling), in a stout closed bottle, cuprous chloride and free sulphur are formed in large quantities. If the heating be continued for some time, all the free sulphur disappears, and sulphuric acid is formed. Under similar circumstances, copper sulphide strongly heated with cupric chloride, air being excluded, yielded copper sulphate and cuprous chloride, no free sulphur being formed. Sulphur strongly heated in a hermetically sealed tube with water, produced sulphuretted hydrogen, but no sulphuric acid. When a 300 per cent. solution of cupric chloride was similarly heated with sulphur, cuprous chloride and copper sulphate were formed. The following equations explain what takes place:—

$$S+H_2O=H_2S+O;$$
$$H_2S+CuCl_2=CuS+2HCl;$$
$$CuS+4O=CuSO_4.$$

Also, $CuS+CuCl_2=Cu_2Cl_2+S$

6. The next point investigated was the action of cuprous chloride, dissolved in a solution of sodium chloride, on silver sulphide. This is a case of simple double decomposition, represented by the formula—

$$Ag_2S+Cu_2Cl_2=2AgCl+Cu_2S.$$

A great many erroneous statements have been made by Malaguti and Durocher, and by others, as to the action of cuprous chloride on mixtures containing silver sulphide. They say that silver is liberated in the metallic state. On this supposition they have built up

various theories relating to amalgamation processes and to geological phenomena. These errors have arisen through their having employed ammonia as a reagent in the investigation of the action of Cu_2Cl_2 on Ag_2S. Ammonia being a solvent for silver chloride, they thought that if the latter were formed by the action of cuprous chloride on silver sulphide, it could be dissolved out from the copper sulphide by ammonia, and then detected by precipitation in the ordinary way. But when ammonia is added to a mixture of AgCl and Cu_2S, it causes double decomposition to take place, Cu_2Cl_2 being re-formed; and $Cu_2Cl_2 + AgCl$, in the presence of ammonia, react upon one another with the formation of $CuCl_2$ and metallic silver. Thus:—

PRIMARY REACTION.

$$2AgCl + Cu_2S + NH_3 = Ag_2S + Cu_2Cl_2.NH_3.$$

SECONDARY REACTION.

$$2AgCl + Cu_2Cl_2.NH_3 = Ag_2 + CuCl_2,NH_3.$$

It was also found that "reversal" takes place when a mixture of silver chloride and copper sulphide is treated with water or sodium chloride solution. No secondary reaction, liberating silver, however, takes place.

It follows from the foregoing that, in order to bring about double decomposition between silver sulphide and copper chloride, the copper chloride solution must be maintained at a certain strength, otherwise the reaction will cease, and anything which caused the solution to be still further diluted would undo a proportionate amount of the work already done.

Sometimes, before commencing to wash up a *torta*, a fresh quantity of mercury is added. The washing is effected in a triple series of circular tanks built of cemented masonry, measuring $9\frac{1}{2}$ ft. wide and $5\frac{1}{3}$ ft. deep, provided with discharge-holes at suitable levels, and with stirring apparatus which can be worked by mules. The mass of amalgam and residue (*lama*), previously softened by watering and treading, is introduced gradually into the first washing-tank in charges of about 4 tons, at the same time that water is admitted, and the stirring apparatus is set in rapid motion; this is continued till the whole of the charge is in, when the speed of the stirrer is reduced by degrees till the mules walk; as soon as the samples then taken from the upper portion of the mass appear pretty free from metal, the slimes are run off, and the operation is repeated on successive charges of *lama* till the *torta* is exhausted. Then the final accumulation of heavy matters at the bottom of the tanks is very carefully collected and washed out either on washing-tables or in *bateas*, to separate the clean amalgam from the other portions, the latter having to undergo further grinding and amalgamating. The treatment of the liquid amalgam will be described later on. The Mexican process is obviously crude and wasteful, resulting in a loss of some 10 to 40 per cent. of the silver in the ore, with an accompanying consumption of 24 to 32 oz. of mercury for every 1 lb. of silver recovered.

(2) Stove Process.—Some modifications of the *patio* process are in vogue in certain districts. In that known as the "stove" process, the operations are identical as far as to the treading, but when this is only half accomplished, the mass is removed to a chamber provided with heating flues beneath the floor, and here subjected to an increased temperature for 2 or 3 days, before completing the treatment on the *patio*. By this plan, the silver return is somewhat increased, but at the expense of a greater waste of mercury.

(3) Hot-water Process.—A hot-water process is employed on ores rich in native silver, or where the metal exists as a bromide, chloride, or iodide. The stamped and ground ore (not too fine) is washed, and charged into a vessel with wooden sides and copper bottom, with sufficient water to make it into a thin paste. The size of the vessel, which is tub-like in form, may vary from that of a *cazo* (3 ft. diameter at top, 2 ft. at bottom, and 18 in. deep), capable of

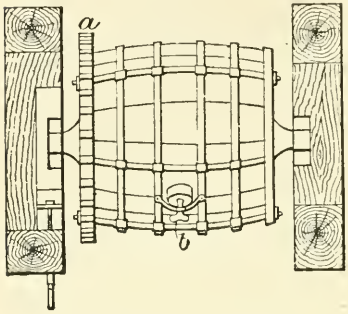
holding about 100 lb. of ore, to that of a *fondon* (5½ to 7½ ft. diameter at the bottom), holding 1200 to 1500 lb. In either case, the contents are heated to boiling by a fire playing upon the copper bottom, and at this point 5 to 10 per cent. of common salt is thrown in and thoroughly stirred up, by hand in the smaller vessel, but by rotating arms carrying lumps of copper, worked by mule power, in the larger vessel. After the salt is introduced, the attendant keeps up a gradual supply of mercury, until samples withdrawn at frequent intervals show that the silver is pretty completely extracted; the estimated requirement of mercury is twice the weight of silver present in the ore, and the cooking operation generally lasts about 6 hours. The *rationale* of the process is that the copper of the vessel decomposes the silver bromide, chloride, or iodide, itself uniting with bromine, chlorine, and iodine, and liberating the silver in a metallic condition free for amalgamation by the mercury. But any sulphide of the metal is not so affected, consequently the residual mass is transferred to the *patio* to undergo treading in the usual manner, except that no addition of *magistral* is needed, as sufficient copper chloride is present to effect the conversion of the silver sulphide into chloride. In this process, the mercury loss is reduced to 2 or 3 per cent., mainly by reason of the fact that the reductiou of the silver chloride is effected at the expense of the copper utensil instead of the mercury.

(4) Barrel process.—"Barrel amalgamation" is the term applied to a method introduced nearly 100 years ago at Freiberg, Saxony, for treating ores containing silver associated with antimony, arsenic, copper, iron, lead, sulphur, and zinc, with occasionally bismuth, cobalt, gold, and nickel. The ores are classified and assorted so that the lead present does not exceed a proportion of 4 per cent. of the total bulk, nor the copper 1 per cent.; and they are divided into 2 grades,—a richer, in which the silver amounts to 90 to 130 oz. per ton, and a poorer giving only 30 to 40 oz. An essential condition in each case is the presence of about 25 per cent. of iron sulphide, for conversion into sulphate during the roasting; if this is not sufficiently supplied by the iron-pyrites in the ore, the deficiency must be made up, whilst if the ore affords too much, part must be abstracted by previous roasting of the portions richest in sulphur. The prepared ore is spread in a thin layer, covered with 10 per cent. of salt, thoroughly mixed together, passed through a coarse sieve, and piled in heaps of 4½ to 5 cwt. each, ready for roasting in reverberatory furnaces. For this purpose the charge is spread on the hearth, and gently heated for 20 to 30 minutes to drive off the moisture, which is facilitated by constant stirring. After breaking down the concretions formed at this stage the fire is urged till dense white fumes are evolved from the charge; this is continued for about 3 hours, during which time the stirring of the mass is kept up; and then the fire is allowed to burn down, but the stirring is maintained till the charge becomes dark throughout and gives off no sulphurous odour. At this stage the mass has become oxidized, and is in a very friable state, occupying an increased space. On again raising the heat for about ¾ hour, the iron sulphate formed from the pyrites decomposes the salt and liberates chlorine and hydrochloric acid, which attack the metals present, and form chlorides, together with some sodium sulphate. The roasted charge is withdrawn, cooled, and passed through sieves; the fine portion passing through is ground to impalpable powder ready for the amalgamation process, while those portions which do not go through the sieves are calcined anew.

Amalgamation is performed in a set of revolving barrels, one of which is shown in Fig. 160. It measures 2 ft. 8 in. long, and 2 ft. 8 in. and 2 ft. 10 in. in diameter at the ends and middle respectively; it is constructed of 3½-in. pine, strengthened by iron hoops and binders, and is provided at one end with a toothed wheel *a* for

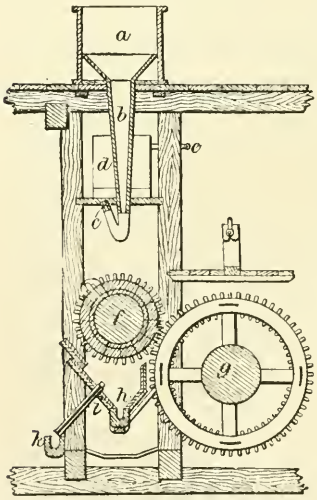
receiving the rotary motion, and in the centre with a 5-in. plug-hole *b* by

FIG. 160.



which it is charged and emptied. The arrangement of the barrels, feeding-hoppers, escape-troughs, and motive power is better illustrated in Fig. 161.

FIG. 161.



The prepared ore is placed in the hopper *a*, one of which is over each barrel, and provided with a wooden spout *b*, whose lower end is joined to a piece of canvas hose, and terminates in a cylinder of tin plate *c*; *d* are water-tanks supplied by pumps through means of pipes *e*; below each barrel *f*, which is caused to rotate by the cogs on the wheel *g*, is situated a triangular trough *h* for catching the matters discharged from the barrel. At starting, 3 cwt. of water is run into each barrel, then 10 cwt. of ore is let in through the spout *b*, and, in addition, 80 to 100 lb. wrought iron in fragments 1 in. square and $\frac{3}{8}$ in. thick are introduced and periodically replaced as they become consumed by the chemical action which ensues in the barrels. The barrels being charged and their plugs secured, they are set to rotate, at the rate of 12 to 15 revolutions per minute, for 2 hours. The contents are then examined, and the consistence of the mass is adjusted by adding a little water or ore as may be necessary; this done, 5 cwt. mercury is introduced, and the barrel is rotated again for 16 hours at 13 revolutions a minute, being twice examined, at intervals of 4 hours, as to the consistence of its contents, so as to ensure that the mercury is neither too much broken up by the mass being over thick, nor left at the bottom by its being too thin. The chemical action generated within the barrel is evidenced by the increased temperature of its exterior. After 18 hours, the barrel is filled up with water, and set to rotate for 1½ to 2 hours at 6 to 8 revolutions per minute, by which the mercury is separated from the other materials and collected in one mass; each barrel in succession is then thrown out of gear and stopped with its outlet uppermost; a little pin in the centre of the plug is removed, and replaced by a tube attached to a length of small hose; the barrel is then turned with its outlet downwards, when the mercury escapes through the pin hole into the hose, and runs down the tube *i* into a gutter *k* for collection and re-use. On the barrel being turned mouth upwards again, the large plug is withdrawn, and the barrel is turned over so that all the contents may escape into the gutter *h*, by which they flow to large underground tanks,

The nature of the changes which take place in the contents of the barrel, and the products resulting from them, may be summarized thus. The first 2 hours' agitation without mercury witnesses the reduction of the chlorides to protochlorides, the solution of the saline matters by the water, and the exposure of the particles of silver chloride. This last is decomposed by the constant and prolonged friction with the mercury and metallic iron, resulting in iron chloride and silver amalgam, with which latter are associated any copper or lead which would have simultaneously suffered reduction from their chlorides.

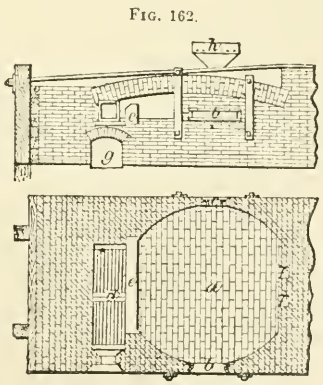
The mass run from the barrels to the underground tanks mentioned at the end of the last paragraph but one, is diluted with water, and kept in constant motion by revolving iron arms; outlets at various depths in the sides of the tanks allow the muddy waters to escape into settling-tanks, where the solid matters are deposited; these are examined for their yield of silver, and should this amount to 4½ oz. per ton, they are dried, subjected to a second roasting with 15 or 16 per cent. pyrites and 5 or 6 per cent. salt, and the residues are sifted and amalgamated in the barrel for a rather shorter period than the bulk of the mass. The mercury which accumulates in the washing-tanks and settlers is periodically collected and treated separately from that run directly from the barrels, which treatment will be described presently. The barrel process of amalgamation entails a loss of about 5 to 10 per cent. of the silver, and an expenditure of mercury equal to ⅕ to ¼ of the weight of silver extracted.

(5) Krölinke's process has been successfully applied in Chili to silver ores containing complex sulphides rendering them unsuited to the *patio* process. The sulphides are decomposed by the employment of cuprous chloride, prepared by heating metallic copper with a solution of copper sulphate and common salt; and amalgamation is effected by mercury and zinc, agitated with the ore in closed barrels, such as have just been described.

(6) Washoe process.—This was devised for treating the vast masses of comparatively poor argentiferous ores found in districts in Nevada, where labour, fuel, necessaries, and transport are too costly to admit of the adoption of any of the methods already described. The ore is divided into 3 classes, according to its character. The first class embraces all mineral assaying over 30*l.* worth of metal per ton of 2000 lb., and in which the silver is intimately associated with antimony, arsenic, iron, and lead; the second class includes material affording 18*l.* to 30*l.* worth of metal; and the third class comprises all workable stuff of a lower value than 18*l.* per ton.

First-class ores are crushed dry, roasted with salt in reverberatory furnaces, and submitted to barrel amalgamation. The reverberatory furnaces are of the form shown in Fig. 162, and

Fig. 162.

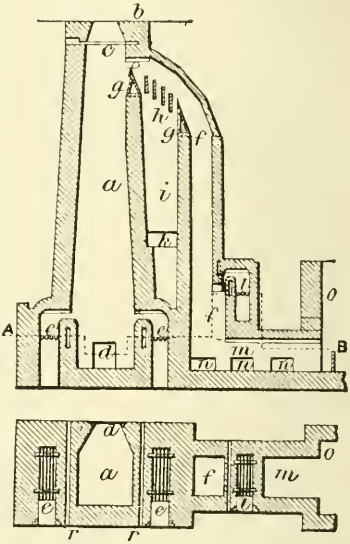


are built of common red brick; *a* is the hearth; *b*, stirring door; *c*, discharge door; *d*, grate; *e*, bridge; *f*, flues; *g*, ashpit; *h*, hopper. The charge consists of 1000 lb. ore mixed with 6 per cent. salt, the latter being added to the ore in the hopper. The charge is heated very gently at first, and the temperature is gradually increased

towards the end, 6 hours being the usual duration of a roasting; the charge is constantly stirred, and turned right over once or twice. The effect produced by the roasting with salt is, stated briefly, first the oxidation of the metallic compounds, converting the sulphides into sulphates, and next the decomposition of these sulphates by the salt, with consequent formation of metallic chlorides. Sometimes a little limestone is added to the charge, for the purpose of decomposing the copper and zinc chlorides, and thus in a measure preventing their subsequent amalgamation, along with the silver in the barrel. A furnace roasting 4 charges of 1000 lb. each in 24 hours consumes 1 cord of wood, and employs 2 men stirring on each 12-hour shift. The roasted ore is passed through a screen with 1600 holes to the sq. in., to remove any caked lumps or coarse particles, and thence passes to the amalgamating barrels, which do not differ in any essential particular from those already described on pp. 413–4.

The common reverberatory furnace is often replaced by one recently introduced by Stetefeldt, the main feature of which consists in allowing the mixture of ore-powder and salt to meet an ascending current of hot air in a shaft, this plan obviating the need of so much labour for stirring the charge, and better ensuring its complete subjection to the action of the heat. The furnace (Fig. 163) consists essentially of a shaft *a*, about 20 ft. high and 3 to 4 ft. square at the base, where are situated 2 fireplaces *e*, whose products of combustion are led into the main shaft *a*, by short flues. On the top *b* of the shaft is placed an automatic feeding apparatus for regulating the admission of materials, with a damper *c* just beneath it; and somewhat lower down the shaft is a flue *f*, into which the heated gases pass around the triangular cast-iron flue-bridges *g*. The cast-iron plates *h* impede the progress of any solid matters which may be mechanically suspended in the vapours, and cause such to fall into the well *i*, whence they can be discharged at *k*. The auxiliary fireplace *l* provides additional heat in the flue *f*, and this prolongs the chemical action. The chief portion of the ore in a roasted and "chloridized" (the metallic constituents converted into

FIG. 163.



chlorides) state is withdrawn at the door *d* in the base of the shaft, while similar doors *n* allow of the removal of the deposit which accrues in the flue *m* and dust-chamber *o*; the draft through the whole furnace is produced by a chimney shaft about 60 ft. high, at the end of the dust-chamber. Common bricks are used in the construction, except for the fireplaces and arches; the walls are built double with spaces between; and the whole structure is tied by iron rails and $\frac{3}{8}$-in. rods. The dust-chamber may be roofed with iron plates, on which to dry the pulverized ore before roasting. The ore is first mixed with salt on a drying floor, and stamped dry; then it is "elevated" to the hopper of the feeder at the top of

the furnace, for continuous supply to the chloridizing shaft *a*. This last is maintained at as even a temperature as possible, and sufficiently high to keep at red heat the ore which collects at the bottom. A furnace worked by 8 men can chloridize as much ore as 10 reverberatories employing 36 men, with a consumption of only $\frac{1}{3}$ the quantity of fuel, and but 3 to 6 per cent. of salt, while about 90 per cent. of the silver present is converted into chloride. The chief difficulty is in securing a regular and constant feed, owing to the liability of the ore to form cakes.

Second and third-class ores, which are often not distinguished from each other, are reserved for the Washoe or pan treatment. They pass through the usual crushing and stamping processes, employing extensive apparatus whose numerous and varied forms may be studied at length in André's 'Mining Machinery' and in Lock's 'Gold,' and are then ready for amalgamation in "pans." These latter vary considerably in detail of construction, as may be seen by reference to the works just quoted; but are alike in their general form and object. They consist essentially of circular vessels with cast-iron bottoms, and cast-iron or wooden walls, penetrated perpendicularly by a shaft which carries a rotating muller, and provided with a cast-iron false bottom. The pan is charged with ore and water in such proportions that the mixture is of suitable consistence, the muller being meanwhile raised; the mass is then heated to a temperature of 185° F. (85° C.) by the injection of free steam into the interior of the pan, and is maintained at this point in many cases by the use of a steam jacket; the muller is lowered by degrees, and rotated for about 2 hours, by which time the mass should have become a soft pulp; mercury (about 60 to 70 lb. for a charge of 1200 to 1500 lb. ore) is is then added by squeezing it through canvas so as to render it more easily disseminated, and the muller is rotated for another 2 or 3 hours, but at a distance from the bottom, so as to act rather as a stirrer. Sometimes small quantities of copper sulphate and salt are introduced into the pan, but without any marked benefit resulting. When the treatment in the pan is regarded as complete, the mass is diluted by the addition of water through a flexible hose, and then run into a series of separators, settlers, or agitators, placed at a lower level, and designed to effect the separation of the amalgam and unamalgamated mercury from the worthless materials. These separators bear a general resemblance to the pans just described, but the muller is replaced by a set of revolving arms carrying wooden blades. Abundance of water is kept supplied to the apparatus while it is in motion, and this carries off the lighter valueless stuff through plug-holes situated at various levels in the side. The speed of the revolving stirrer and the quantity of water require to be nicely adjusted to suit the demands of the case, so as to completely draw off the waste matters and leave all the mercury and amalgam at the bottom. The waste tailings are run over blanket-tables and other contrivances for catching any stray particles of metal not eliminated by the separator. The amalgam collected is treated as all others are done.

The chemistry of the Washoe process is summarized by Arnold Hague thus:—(1) The ore consists chiefly of native gold, native silver, and argentiferous sulphides, associated with varying proportions of blende and galena; (2) the action of the sodium chloride and copper sulphate in the pan produces copper chloride; (3) the presence of metallic iron causes formation of copper sub-chloride; (4) both the copper chlorides assist in the reduction of the ore by chloridizing the silver sulphides and decomposing the lead and zinc sulphides; (5) copper sulphate enhances the amalgamating energy of the mercury, by causing the formation of a small quantity of copper amalgam, while it also tends to expel the lead; (6) notwithstanding the importance of

chemical agents as just indicated, the quantities added to the pulp in the ordinary practice of Washoe mills are too small to effect any very beneficial results; (7) the mercury and iron, aided by heat and friction, are the principal agents concerned; (8) an essential condition for amalgamation is that the mercury be kept perfectly bright and pure; (9) the consumption of mercury in the Washoe process is chiefly mechanical, and only in a slight degree chemical.

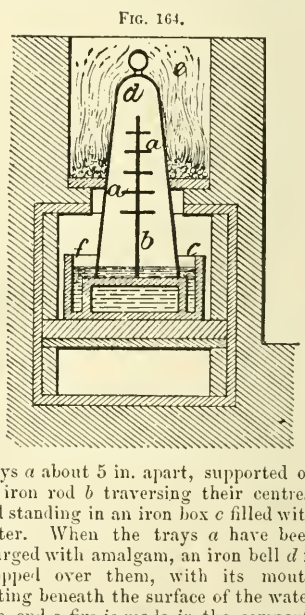
Sodium-amalgam. — It has become pretty general to use a small proportion (say 1 to 2 per cent.) of sodium with the mercury employed for amalgamation. The object of this is to prevent the surface of the mercury being coated with a film of sulphide, by which it is rendered partially inactive and divided into little particles, an occurrence technically known as "flouring" or "sickening"; the sodium acts as a preventive by decomposing the mercury sulphide with consequent formation of sodium sulphide, and leaving the mercury free. The reader interested in this subject will do well to refer to Lock's 'Gold,' where the use of sodium-amalgam and of many other substances for economizing the mercury is discussed at length.

Retorting the Amalgam. — Having obtained an amalgam (or mercury-silver compound) by any of the methods just described, the next step is to effect the separation of the two metals without losing either. This is performed by subjecting the amalgam to heat in a retort which admits of the collection of the mercury thereby distilled over, leaving the metallic silver behind in a free state, and ready for melting into ingots.

Before retorting, the liquid amalgam is first relieved as far as possible of the excess of uncombined mercury. This may be done by placing the mass in a narrow wooden cylinder about 8 ft. high, when the liquid mercury forms a stratum at the bottom; but the separation is more generally effected by squeezing the mass in a canvas bag, when the liquid portion strains through. This liquid portion is not pure mercury, but contains about 20 oz. silver per ton; it is used for amalgamating a fresh lot of ore. The solid portion remaining in the canvas is a pasty mass consisting of about 80 per cent. mercury, and 20 per cent. silver, with small proportions of the various other metals originally present in the ore, especially antimony, bismuth, copper, gold, lead, and zinc. This pasty amalgam, made up into balls, is submitted to distillation in furnaces of varied construction.

A simple form is shown in Fig. 164. The balls of amalgam are put into iron

FIG. 164.

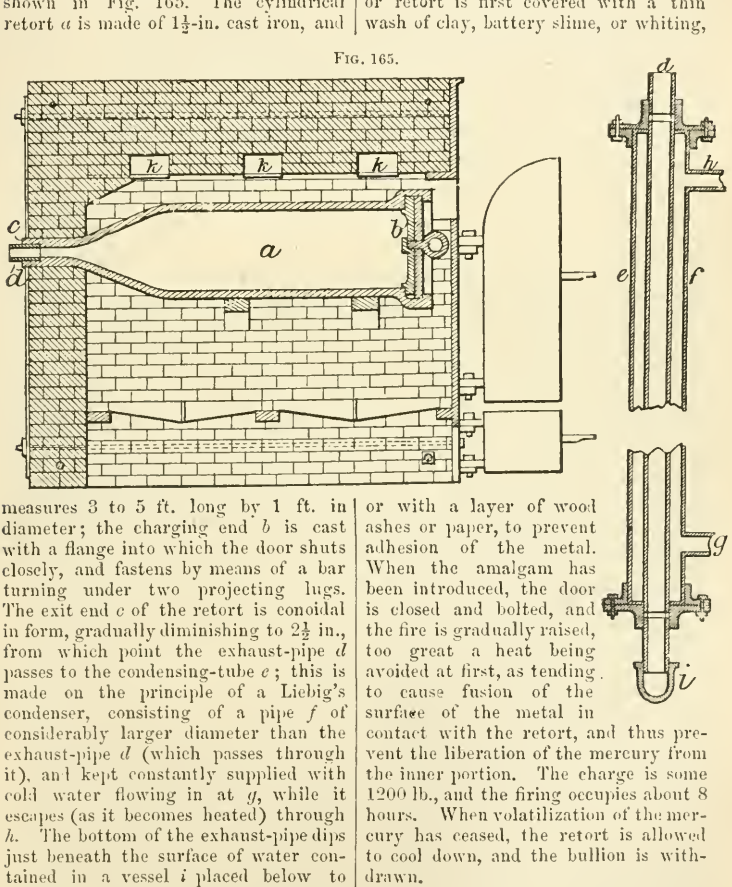


trays *a* about 5 in. apart, supported on an iron rod *b* traversing their centres, and standing in an iron box *c* filled with water. When the trays *a* have been charged with amalgam, an iron bell *d* is dropped over them, with its mouth resting beneath the surface of the water in *c*, and a fire is made in the compartment *e*, successively with wood, peat, and charcoal, so that the upper portion of the bell becomes red hot; the mercury is thereby vaporized, and passes down to the water beneath, where it condenses, the water being kept cool by continually renewed supplies entering the trough *f* in which the iron box

c stands. The distillation of 3 cwt. of amalgam is complete in about 8 hours, when the bell is lifted off, and the spongy masses of impure silver are collected from the trays.

A more modern form of retort is shown in Fig. 165. The cylindrical retort a is made of $1\frac{1}{2}$-in. cast iron, and

Fig. 165.

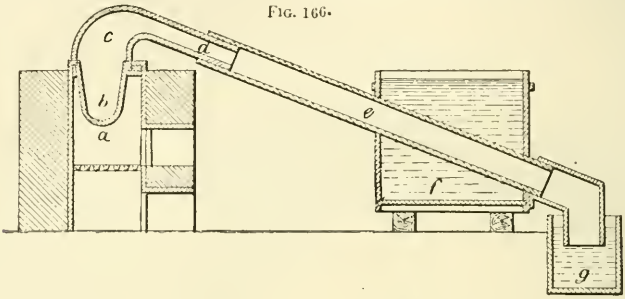


measures 3 to 5 ft. long by 1 ft. in diameter; the charging end b is cast with a flange into which the door shuts closely, and fastens by means of a bar turning under two projecting lugs. The exit end c of the retort is conoidal in form, gradually diminishing to $2\frac{1}{2}$ in., from which point the exhaust-pipe d passes to the condensing-tube e; this is made on the principle of a Liebig's condenser, consisting of a pipe f of considerably larger diameter than the exhaust-pipe d (which passes through it), and kept constantly supplied with cold water flowing in at g, while it escapes (as it becomes heated) through h. The bottom of the exhaust-pipe dips just beneath the surface of water contained in a vessel i placed below to catch the condensing mercury. The retort is set in a brickwork furnace of simple construction, resting either on an arch or on iron bars, with a fireplace extending its full length beneath, and a vault above communicating with the chimney by flues k. The amalgam is either charged directly upon the bottom of the retort, or put into trays of suitable shape. The surface of the trays or retort is first covered with a thin wash of clay, battery slime, or whiting, or with a layer of wood ashes or paper, to prevent adhesion of the metal. When the amalgam has been introduced, the door is closed and bolted, and the fire is gradually raised, too great a heat being avoided at first, as tending to cause fusion of the surface of the metal in contact with the retort, and thus prevent the liberation of the mercury from the inner portion. The charge is some 1200 lb., and the firing occupies about 8 hours. When volatilization of the mercury has ceased, the retort is allowed to cool down, and the bullion is withdrawn.

Fig. 166 illustrates another modern form of distilling apparatus, consisting of a charcoal fire a which heats an iron crucible b measuring 22 in. wide and

11 in. deep; the vaporized mercury is collected in the iron hood *c*, and passes by the swan-neck *d* into the condensing tube *e*, which traverses a cistern of

FIG. 166.



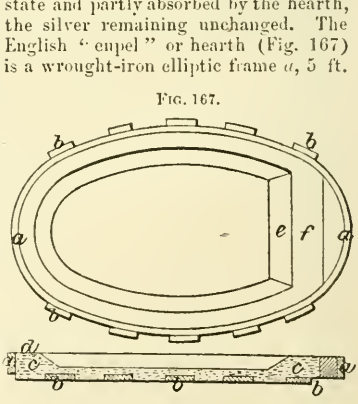
water *f*, escaping at *g* into a suitable receptacle. The inside of the crucible is coated with lime wash, and an iron plate similarly coated is fitted into the crucible, and withdrawn with the silver adhering to it at the close of the operation. The charge is 4 cwt., and the duration is 5 hours.

Melting the Metal.—The impure metal left after the distillation of the mercury is melted down, commonly in crucibles made of a mixture of fire-clay and graphite. During the melting, the mass is briskly stirred with an iron rod, to facilitate the escape of fumes of antimony, bismuth, and zinc oxides, and the formation of a dross containing copper and lead oxides, which is skimmed off as long as any appears, after which, the metal is cast into ingots. Where very large quantities are dealt with, a furnace holding several egg-shaped retorts is employed for the melting.

(*b*) Cupellation and Eliquation.—The process known as cupellation is performed with the object of separating silver from lead by the oxidation of the latter. In this country, it is mostly employed on the highly argentiferous lead obtained by the Pattinson desilverizing method, as described under Lead, p. 354. The chief object is generally the recovery of the metallic silver in a purer condition, but sometimes the lead oxide (litharge) is the article mainly sought, and then the purification of the silver takes a secondary place. The details of the cupellation process are subject to a variety of modifications, but there are only two essentially different plans, known respectively as the English and the German.

(1) English process.—The operation consists in exposing the silver-lead to the action of air at a high temperature on a porous hearth, by which the lead oxide is partly removed in a liquid state and partly absorbed by the hearth, the silver remaining unchanged. The English "cupel" or hearth (Fig. 167) is a wrought-iron elliptic frame *a*, 5 ft.

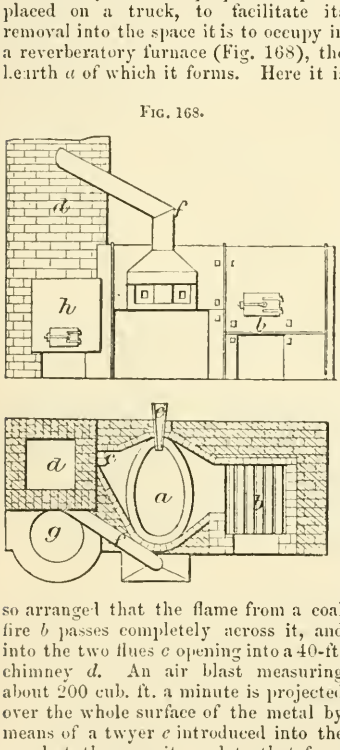
FIG. 167.



by 2¼ ft., crossed by 5 iron bars *b* 3¾ in. wide, and filled with bone-ash *c* moistened with water containing a little potash carbonate; this bone-ash filling is well beaten down and dished out till

it is only $\frac{3}{4}$ in. thick over the bars, but leaving a rim *d* 2 in. wide all round, except at the end *c*, where it is 5 in. wide, and through which (the "breast" of the cupel) a channel *f* is cut to allow the liquid lead oxide to flow away into a receptacle without coming into contact with the iron rim, which would be attacked by it. The prepared cupel is placed on a truck, to facilitate its removal into the space it is to occupy in a reverberatory furnace (Fig. 168), the hearth *a* of which it forms. Here it is

Fig. 168.

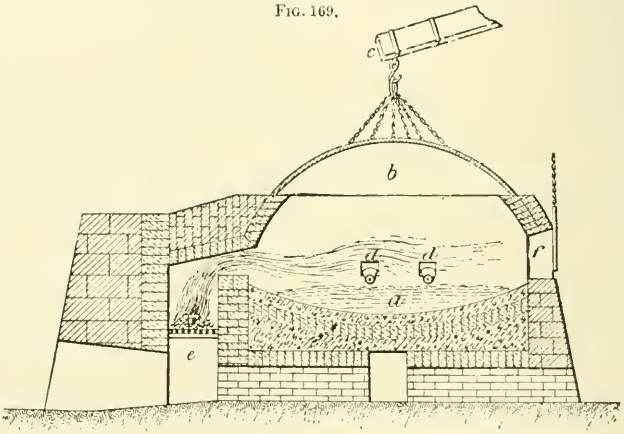


so arranged that the flame from a coal fire *b* passes completely across it, and into the two flues *c* opening into a 40-ft. chimney *d*. An air blast measuring about 200 cub. ft. a minute is projected over the whole surface of the metal by means of a twyer *e* introduced into the cupel at the opposite end to that from which the lead oxide escapes, and provided with a hood and pipe *f* for conveying the fumes into the chimney. The silver-lead is first melted in an iron pot *g* heated by a separate fire *h*, and from this it is ladled into the cupel to the amount of 500 to 600 lb., nearly filling it after it (the cupel) has been very gradually heated almost to redness. As soon as the surface of the metal becomes covered with melted lead oxide, the blast is turned on, and the lead oxide is driven off in waves through a channel cut for it, and into a cast-iron pot placed outside to catch it. As one channel becomes corroded, it is closed, and another is cut; and as the lead disappears from the cupel it is replaced by additions from the melting-pot *g*, so as to maintain an even level. This goes on for some 16 or 18 hours, during which period 4 or 5 tons of lead will have been introduced, leaving an alloy holding about 8 per cent. of silver in the cupel; this is let out through a hole made in the bottom, and cast into ingots. The aperture is closed with fresh bone-ash, and a new charge is supplied, till the cupel is worn out; the life of a cupel does not often exceed 48 hours, with a capacity for treating 5 cwt. an hour. The ingots of metal from the first cupellation, to the amount of about 3 tons, are cupelled anew in the same furnace, but on a hearth provided with a depression in the bottom, capable of containing the mass of residual silver, weighing perhaps 500 lb. The reason for dividing the cupellation into 2 stages is to be sought in the fact that the lead oxide driven off from the highly argentiferous mass carries away an appreciable quantity of silver with it, therefore the lead obtained by smelting it and the cupel is reserved for treatment with the object of recovering this silver, amounting perhaps to 40 oz. per ton. Sometimes a steam-jet is used instead of a blowing machine to supply air for the oxidation of the lead, and this plan is said to afford a better product in a shorter time. Much lead and silver is in any case driven away as vapour, by the force of the blast, and partially condenses as oxide in the flues, whence it can be recovered. The lead oxide is reduced to metallic lead by smelting in a reverberatory furnace with a hearth measuring 8 ft. by 7 ft., lined with bituminous coal, which soon forms a porous coke, capable of protecting the hearth from

corrosion while permitting the fluid metallic lead to escape through its pores. The action of the furnace is very simple, the carbon of the burning fuel uniting with the oxygen of the lead oxide and leaving the lead in a metallic state. The charge for a furnace of the dimensions given is composed of 3 tons lead oxide and 6 cwt. small coal.

(2) German process.—This is adapted for treating leads of low quality, while the English process is only suited to those containing but little antimony and copper. The main difference in the furnaces is that the German (Fig. 169) has a fixed circular hearth *a*, which is covered by an iron dome *b* lined with clay and capable of being removed by a crane *c*; the cupel is about 10 ft. in diameter, and is formed of damp wood ashes, or a mixture of clay and lime, which is dished out and shaped with a central hollow about ½ in. deeper than the rest and 20 in. across, where the silver accumulates. Air is introduced by 2 twyers *d*, and heat is supplied from the fireplace *e*, in which wood is preferably used as fuel. The lead pigs are piled on a straw bed, and the fire is gradually increased (without any blast for the first 3 hours) till the metal is completely fused, when the supernatant scum (*abzug*) is skimmed off through the working door *f*, and the twyers are brought into play to aid the oxidation. The mass is kept at a low-red heat till the impurities cease to separate, and impure litharge (*abstich*) commences to form. A cherry-red heat is then maintained and a full blast is kept up, the litharge being washed in sweeps towards an outlet which requires to be deepened in proportion as the liquid metal sinks in the hearth. When the oxidation has been carried as far as is feasible in this furnace, water is run in by a wooden spout through the door *f* upon the surface of the silver, causing it to solidify. The cupel is renewed when worn out by removing the dome *b*; the impregnated cupel is broken up and smelted for the recovery of the lead and silver which it has absorbed. The lead obtained by the reduction of the litharge first formed is fit only for shot or type-metal, as it contains antimony, iron, and other impurities; whilst the lead from the last portions is largely mixed with silver. The use of a blast heated to 400° F. (204½° C.) effects a notable saving of time and fuel in the cupellation, and permits the treatment of lead associated with 10 or 12 per cent. copper. All

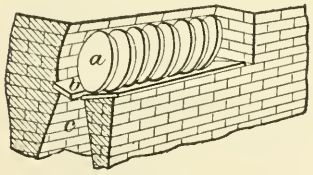
FIG. 169.



the silver separated by cupellation has to undergo a process of purification, described on p. 428.

(3) Eliquation.—This constitutes a preliminary step to cupellation in the case of some ores containing copper. The principle involved in the process is first to extract the silver from the copper by producing a silver-lead alloy, and then to separate the silver from the lead by cupellation. The process is now mostly superseded by the "wet methods," but where it survives it is conducted as follows. The copper is dealt with in the form known as "black copper"; this is broken very small or granulated, and melted with alternate charges of argentiferous lead in a small blast furnace; the copper-lead alloy thus formed is cast into discs measuring 18 in. across and 3 in. thick, by pouring it into thick cast-iron moulds and chilling it with cold water. On a

Fig. 170.

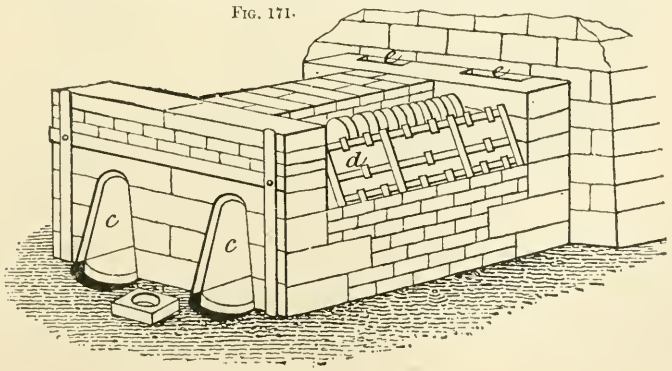


hearth similar to that shown in Fig. 170, the discs *a* are ranged on edge with wooden wedges between, along a trough formed by 2 cast-iron plates *b* inclined towards each other, and heated by a wood fire in the grate *c*. When the gutter is packed with discs, it is closed at the side by an iron plate *d* (Fig. 171), and then all remaining space is filled up with wood charcoal. The heat from the fire in *c* ignites the charcoal, and, as the temperature rises, the lead melts and flows between the plates *b* and out into receptacles placed to catch it at the mouth of the furnace *c*. The fire is regulated by dampers at *e*. After 3 or 4 hours, the lead will have flowed away, carrying the silver with it, and is cast into ingot ready for cupellation.

The residuary copper discs, still containing about 25 per cent. of argentiferous lead, are submitted to greater heat in a sweating furnace (Fig. 172); here they are put over a series of fire-brick stalls *a*, where wood fires are ignited, whose combustion is supported by the draught of the chimney *b* and flues *c*. The lead is mainly oxidized to litharge, much of which, mixed with copper oxide and silver, accumulates in the bottoms of the stalls *a*, and is gathered thence for fusing with the black copper in the liquation hearth.

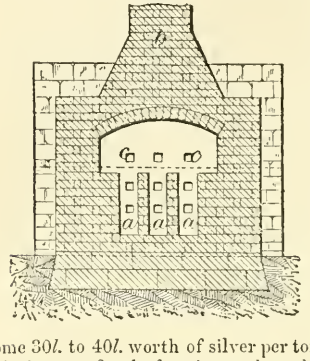
(4) Smelting.—In Nevada, the argentiferous galenas containing much antimony are dealt with in the following manner. The ore is first smelted in a

Fig. 171.



shaft furnace to afford a crude metal consisting of antimony and lead with

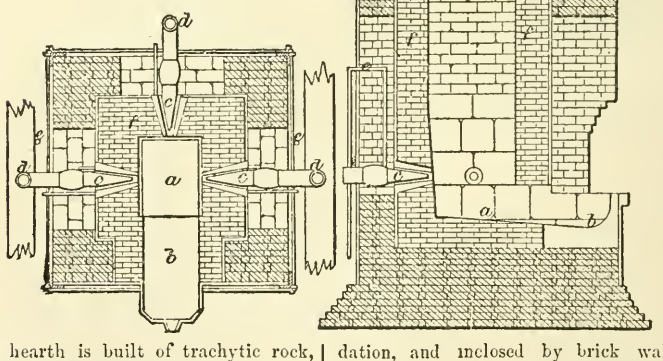
FIG. 172.



some 30*l.* to 40*l.* worth of silver per ton; this is next freed of antimony by calcination in a sublimation furnace; and the silver-lead alloy is finally cupelled on an English hearth. The shaft furnace for smelting the crude ore is shown in Fig. 173. Its total height is about 40 ft.; the hearth is built of trachytic rock, and the shaft is of common brick with a fire-brick lining from the hearth up to the throat; *a* is the hearth or sole; *b*, the sump or receiver into which the metal runs on being tapped from the furnace; *c*, twyers; *d*, blast pipes; *e*, pipes to supply water to the twyers; *f*, furnace lining. The capacity of the furnace is 12 to 13 tons per 24 hours. The ore is broken small, spread upon the charging floor, and mixed with about 25 per cent. of flux, which may be limestone, or slag, or a mixture of both, or litharge from the cupelling furnace; to this is added about 15 bush. wood-charcoal per ton of ore, and some 100 lb. of the mixture is fed in at once, the supply being kept up as the smelting proceeds. When the furnace is in regular operation, the slag is discharged continuously, while the metal is tapped off into an iron sump at intervals of 1 or 2 hours, and is removed thence for casting into ingots. The yield is about 5 tons of crude mixed metal from 12 tons of ore. The charcoal used is made from the "nut pine," and is considered of excellent quality.

The sublimation furnace for the removal of the antimony consists of a cast-iron bath 13 ft. long, 5 ft. 8 in. wide, and 8 in. deep, made of 1-in. metal, supported on a substantial foundation, and inclosed by brick walls 10 in. high, over which an arch is turned. At one end is a fireplace, the flames from which pass over a bridge and thence impinge upon the surface of the metal in the bath. Openings are provided for the admission of air to the

FIG. 173.



charge, and others for introducing the charge and removing the scum which forms on the surface. A tap at the side near one end of the pan permits the refined lead to be drawn off, while a chamber connected with the chimney arrests much of the condensed antimony oxide. At starting, the bath is usually heated to redness, and the pigs of crude metal are introduced and allowed to melt; the charge may be 6 or 8 tons to commence with, and fresh supplies are added as the skimming and oxidation reduce the bulk by removing the antimony. Very little fuel is needed, sometimes even sage-brush sufficing for this purpose. The metallic scum taken off during the calcining constitutes practically an antimony-lead alloy (71 per cent. of the former with 29 of the latter), and is cast into bars and sold for type-founding and similar applications. The lead in the bath gradually becomes enriched in silver, and when it reaches a value of 70*l.* to 80*l.* a ton, it is removed to the cupellation furnace, already described.

(*c*) Wet methods.—This term is applied to those processes in which the metals present in the ore are brought into solution in the form of salts, and are reprecipitated separately. They are mainly as follows.

(1) Augustin's. — This process is adapted for treating speisses and mattes containing 50 to 70 per cent. copper, and free from antimony, arsenic, lead, and zinc. It is divided into 3 stages :— (1) roasting the matte to form sulphates of the metals; (2) roasting with salt to form silver chloride; (3) lixiviating and precipitating the metals. The finely ground and sifted matte is roasted for 10 hours in a reverberatory furnace, when a sample should give a faintly blue solution with hot water, and a precipitate of silver chloride on addition of salt. The charge is then drawn, cooled, ground fine, sifted, mixed with 3 to 5 per cent. common salt, and roasted for 2 or 3 hours at a low temperature in the same furnace. The chloridized ore is transferred to a series of lixiviating-tanks provided with linen strainers supported on a layer of twigs; into these is run a solution of common salt, previously heated by steam-pipes, which dissolves the silver chloride present and carries it off to another series of tubs, where the silver is precipitated in the metallic state by adding cement copper The cupreous liquors are next treated with scrap iron, which causes the metallic copper to go down; and the brine solution, thus completely freed from both silver and copper, is pumped up for re-use on a fresh lot of chloridized ore. By the addition of chlorine water to the brine solution, any gold which may be present is dissolved at the same time with the silver. The silver obtained is washed with hydrochloric acid to remove traces of copper, again with water to remove any adhering acid, and is then made into small balls; these are dried and fused. The copper matte, when exhausted of its silver, is washed with water, and smelted in the ordinary copper furnace. The copper precipitated by the iron is used again instead of cement copper for throwing down the silver. Usually 8 to 12 per cent. of the silver in the ore is lost; and even less satisfactory results are obtained with speisses than with mattes.

(2) Claudet's.—This process was devised to effect the recovery of the precious metals (mainly silver) contained in the liquors resulting from the wet method of extracting copper from Spanish and Portuguese pyrites. The first 3 washings contain 95 per cent. of the silver yielded by the wash-waters, and these alone are treated. The silver is extracted as an iodide, in the following manner. The liquor is allowed to settle for a time in a capacious vat, and is then run into another of somewhat greater capacity, where it receives an addition of a soluble iodide in just sufficient quantity to precipitate the silver ascertained to be present, and about $\frac{1}{10}$ of the volume of the liquor of water; the whole is stirred thoroughly during the filling, and settled for 48 hours. The clear liquor is then run off, and the accumulated sediment is col-

lected once a fortnight. The latter consists essentially of lead (sulphate and chloride), silver (iodide), and copper (subsalts); the copper salts are removed by washing with water containing hydrochloric acid, and the precipitate is decomposed by metallic zinc, from which result (1) a precipitate rich in silver and containing some gold, and (2) a zinc iodide which is used for precipitating fresh quantities of silver. The chief components of the precipitate are 56 per cent. lead, 15 per cent. zinc, about 1450 oz. silver per ton, and 15 to 20 oz. gold per ton; or, on a working scale, over $\frac{1}{2}$ oz. silver and 3 gr. gold are recovered from each ton of pyrites, at a total cost of 8*d*. per ton. (Phillips.)

(3) Cumenge's.—Ores containing large quantities of antimony, arsenic, copper, and silver are successfully treated by Cumenge's process, which is a combination of dry and wet methods. It is based on the oxidation of antimony and arsenic by injection of steam during the preliminary roasting, and on the fact that this oxidation is limited by the presence of the hydrogen set at liberty; this latter combines with the antimony, the arsenic, and the sulphur, effecting at once the elimination of these troublesome bodies in the form of volatile products. But this plan presents serious inconveniences in the shape of the long duration of the operation and the cost of the steam; these have been largely overcome by introducing a maximum of 5 per cent. of soda nitrate into the furnace, which renders the oxidation much more active, and causes an increased production of sulphuric acid from the sulphur present, with consequent formation of soluble double salts. Nevertheless the reducing influences still have sufficient effect to prevent the iron present being oxidized to the utmost; while the antimony and arsenic are almost completely removed by volatilization. The silver is mainly sulphatized, but a certain portion is reduced to the metallic state during or after the action of the iron subsalts. All these reactions are clean and easily realized, but it is essential that the ore be first submitted to smelting in a cupola furnace, to remove great part of the earthy matters; it is the matte thus obtained, weighing only $\frac{1}{10}$ to $\frac{1}{20}$ of the original mass of ore, that is powdered and roasted. The sulphatized silver is dissolved in 5 or 6 times its weight of hot water, and precipitated by copper, iron being then used to recover the copper. The roasting with the soda nitrate is conducted in fire-clay vessels resembling gas retorts, the pulverized mineral being spread about $\frac{1}{2}$ in. thick and constantly stirred to prevent agglomeration. The roasting is continued for 8 hours with steam alone (superheated by preference); the soda nitrate is then added; next follows another roasting for 4 hours, the nitrate being thus introduced towards the end of the operation to prevent formation of silver and soda antimonates and arsenates; finally, 4 hours' roasting effects the sulphatization of the silver. The heat of the retort should be carefully maintained between dark-redness and cherry-redness.

(4) Hunt and Douglas's.—This process is based on the difference of solubility of the chlorides, and consists of the following operations. The mineral, after being submitted to ordinary chlorination, is put into wooden vats furnished with stirring-arms, and a solution of iron and sodium chlorides, called "Hunt and Douglas liquor," is kept in contact with it for 4 or 5 hours, the whole mass being meantime heated by steam and subjected to an atmosphere of sulphurous acid. Under the influence of the various chlorides introduced or formed, the silver salts which have resisted the first chlorination process are converted into chloride; after roasting, the liquid portion is drawn off, and the residue is washed with hot water, by which the iron and copper chlorides are removed. Then, in the same vessels, the silver chloride is dissolved by adding lime hyposulphite, the temperature being raised to 100° F. (38° C.), and the whole is stirred for about 3 hours. After washing the residues, nearly all

the silver originally in the ore will be found in the more or less concentrated liquors, and may be precipitated as sulphide by adding calcium sulphide. It remains to wash the precipitate, dry it, and roast it at a low temperature in a small reverberatory furnace, to remove accidental impurities, which will be minimized by conducting the hot-water washing with great care. The products employed undergo revivification: the liquor drawn from the vats is filtered, and its copper is recovered by adding metallic iron. The lime hyposulphite liquor, after precipitation of the silver, always contains a slight excess of the calcium sulphide employed: by passing a current of sulphurous acid, the sulphide is transformed into hyposulphite.

(5) Maxwell-Lyte's. — This is described under Lead, pp. 350–3.

(6) Percy and Patera's.—This process is suitable only for ores containing 2 per cent. and upwards of silver, though the presence of antimony, arsenic, bismuth, cobalt, copper, iron, lead, nickel, and sulphur does not interfere with it. The preliminary step is roasting the comminuted ore with 6 to 12 per cent. common salt and 2 to 3 per cent. iron sulphate in a furnace to which steam is admitted. The mass is next washed with hot water for 6 hours, by which the chlorides and sulphates of the metals other than silver are carried away in solution. The silver chloride deposit in the washing-vats is treated with cold dilute sodium hyposulphite solution, which dissolves the silver. From this solution the silver is precipitated by means of a solution consisting chiefly of sodium pentasulphide with a little sodium hyposulphite, obtained by fusing soda-ash with sulphur and boiling the aqueous solution of the product with excess of sulphur. The silver sulphide is deposited in about 6 hours as a slimy mud; this is strained through canvas, washed, dried, heated to redness in presence of free air, and fused in graphite crucibles with addition of metallic iron; the scum thus produced is removed and used as a substitute for the iron sulphate in the first roasting, and finally the application of a little bone-ash and wood-ashes cleanses the surface of the metallic silver, and leaves it ready for casting.

(7) Sulphuric acid.—Nearly all the silver and gold contained in copper mattes may be extracted by treatment with hot dilute sulphuric acid, when the copper forms a solution of sulphate. The process is applicable to materials containing antimony, arsenic, and lead, but not iron. The finely granulated metal (preferably black copper) is moistened with the acid and exposed to the air; fresh supplies of the acid are added to dissolve the sulphate formed, and this solution is allowed to run through a long leaden trough, in which the cooling liquor deposits imperfect crystals of copper sulphate and a muddy sediment containing the silver and gold. The strongly acid liquor flowing away clear is re-used on the copper, while the accumulated matters in the trough are removed and dissolved, when the copper sulphate forms almost pure crystals, and the silver-gold mud is liberated. This latter is smelted with litharge so as to afford a silver-lead alloy containing 2 per cent. of the more valuable metal; the alloy is cupelled, and yields a silver holding about $1\frac{1}{2}$ to $1\frac{3}{4}$ per cent. gold. The copper sulphate produced in the process is sold in that form.

(8) Ziervogel's. — The basis of this process is the fact that on roasting argentiferous copper- and iron-pyrites (sulphides), the iron is converted successively into ferrous sulphate, ferric sulphate, and ferric oxide; the copper into cupric sulphate and cupric oxide, the sulphuric anhydride being expelled; and the silver into sulphate. On lixiviation, the silver sulphate passes into solution, from which it can be precipitated in the metallic form. The process is well suited for treating copper mattes containing 80 per cent. copper subsulphide, 11 of iron sulphide, and 0·4 of silver sulphide, without appreciable quantities of antimony, arsenic, lead, and zinc. The material to be operated on is granulated, ground

fine, sifted, and roasted in a reverberatory furnace in contact with fuel for about 10 hours, care being taken to stir it frequently. The roasted mass is taken to vats and there treated with hot water containing a little sulphuric acid, till common salt gives no precipitate in the liquor running away. The subsequent treatment of the silver sulphate solution, first with copper to throw down the silver, and then with iron to recover the copper, presents no novel feature. The whole success of the process depends upon the roasting in the reverberatory furnace, which is a delicate and difficult operation. At the same time, in dealing with such materials as mentioned before, the process is said to be the most effective and least costly of all.

Purification.—Commercial silver is never pure, traces of copper and gold being universally present. For coinage purposes, these impurities are not detrimental; but for analytical applications, greater purity is necessary. This may be attained by boiling well-washed silver chloride with caustic potash and sugar; when the metal is completely reduced (as ascertained by a well-washed sample dissolving completely in pure dilute nitric acid), it is melted with pure sodium carbonate in a crucible. To obtain absolutely pure silver, the following plans are in use:—(1) The ordinary metal is dissolved in pure nitric acid, leaving a residue of gold; the solution is evaporated to dryness, and the residue is fused to eliminate accidental traces of platinum nitrate, and then dissolved in dilute ammonia solution; the solution is filtered, and the filtrate is diluted till the silver present amounts to 2 per cent.; enough normal ammonium sulphite solution is added to destroy all colour on heating, and the mixture is left for 24 hours in sealed bottles; about 33 per cent. of the silver crystallizes out, and the remainder is thrown down on heating the solution to 140° to 158° F. (60° to 70° C.); the metal is washed with water, and left in contact with concentrated ammonia for some days, to get rid of any remaining copper; after another washing and drying, it is melted with 5 per cent. each of sodium nitrate and fused borax in an unglazed porcelain crucible, and then cast in moulds coated with a mixture of burnt and unburnt china clay; the bars are cleaned with sand, heated with potash to destroy attached silicate, and washed with water. (Roscoe and Schorlemmer.) (2) Commercial fine silver is dissolved in dilute nitric acid, the solution is evaporated to dryness, and the residue is fused till red fumes cease to come off, dissolved in water, filtered, and diluted with 30 parts filtered rain-water to each one of silver; the silver is precipitated as chloride by adding pure hydrochloric acid, washed with dilute hydrochloric acid and with water, dried, triturated in a mortar, repeatedly digested with aqua-regia, well washed, and reduced by boiling with pure dilute caustic potash in presence of milk sugar; finally the metal is washed with dilute sulphuric acid and with water, and then dried and fused. (Stas.)

Properties and Uses.—Metallic silver has a sp. gr. of 10·424 to 10·57, a pure white colour, and a fusing temperature of about 1904° F. (1040° C.); it is extremely malleable and tough, and the best conductor of heat and electricity; it offers great resistance to oxidation, and is not affected by fused caustic alkali. Its chief applications are for coinage purposes, when it is always alloyed with more or less copper; and for ornamental objects, whether in the solid form or as a thin coating on some cheaper base. The surfaces of standard silver articles are sometimes given a "frosted" appearance by heating till a thin skin has had its copper oxidized, then removing this oxide by immersion in ammonia or dilute sulphuric acid, thus leaving only pure silver showing.

SLAG.—The disposal of the enormous output of slag or scoria from blast furnaces has always been one of the serious difficulties of the iron trade. Taking an average of all the districts in England, for each ton of iron made, 25 cwt. of slag is produced; and from

the official returns of 1879 of the iron smelted, no less than 8,000,000 tons of slag were produced. The space occupied by this mass, when loosely tipped, is something like 170,000,000 cub. ft., whilst the bulk of the iron occupies only $\frac{1}{6}$ of the same space. There is, however, this great difference between iron and its refuse, that, whilst the former is diffused and finds its way into every corner of the world, the latter is left behind at the smelting-works, absorbing something like 250,000*l.* annually in its disposal, and destroying hundreds of acres of valuable agricultural land. While we produce such enormous quantities of iron, so long will these heaps go on accumulating; and there is little chance that existing masses will ever be turned into a marketable product. At the same time, blast-furnace slag possesses many valuable properties, which may in certain localities be converted into things useful to the arts and sciences, and at considerable profit.

Of other slags produced in metallurgical operations—such as in the smelting of copper, lead, zinc, and tin ores—no use is made; but there are also slags, or cinders, produced in the manufacture of wrought iron, some of which are re-smelted, after which no great bulk of refuse is left.

Blast-furnace slag, as it flows from the furnace when making foundry iron, is usually of a grey colour, of much the same consistency as molten glass, a substance, in many points, it greatly resembles, particularly when the more siliceous ores are being smelted. It is very fluid, and has a temperature considerably above the melting-point of cast iron; in proof of which, if a piece of cold cast iron be placed in a block or wagon of fresh molten slag, it readily melts. At this high temperature it contains a large quantity of gas, a considerable portion of which is thrown off or exuded as the slag cools down or becomes set. So much is this the case, that a large "block' or "ball," technically so termed, will often burst, an hour or two after being run, from the accumulation of this gas in the inside. The bursting of these balls at the iron-works is of constant occurrence, and a source of danger, caused by the liquid slag and the outside shell dropping after the ball has burst. This is partially overcome by making the workmen knock a hole through the top crust before leaving the furnaces. Again, the least derangement in working the furnace is quite sufficient to alter the nature of the slag, and often, within $\frac{1}{2}$ hour, will the slag be changed from grey to a perfect black. Such a colour usually indicates imperfect smelting, and the slag will be found to contain a larger proportion of iron than it should do.

For Road-metal.—For many years the only known use for blast-furnace slag was in road-making, and for this purpose it is still largely employed. In Northamptonshire, and in certain districts of Yorkshire, the whole of the slag produced is sold at a considerable profit. These, however, are local exceptions. Large quantities of slag are used in the works on the breakwater at the Tees mouth, something like 500,000 tons annually. A similar class of work is carried on at Barrow-in-Furness, from the slag produced at the hematite furnaces in that town; but in consequence of the large amount of lime contained in this slag, much greater care has to be taken in its selection. The slag used at the Tees breakwater is chiefly taken away upon bogies, in blocks weighing $3\frac{1}{2}$ tons each. The slag is run into these blocks upon the waggons at the furnaces, a case or box being placed upon the bogie for this purpose. When the slag is sufficiently "set," this case is removed, and the waggon, with the block upon it, is taken a distance of about 6 miles to the breakwater. A large quantity is also tipped upon a platform on the riverside, in such a position that the tide completely covers it; it is then wheeled into hopper barges. Fowler and Wood devised a plan for shipping the bogies with the hot balls into barges, and towing them down the river for discharging; each barge is constructed to carry 40 bogies and is about 220 tons burden. The loading of

these barges at all states of the tide has necessitated the construction of special machinery by Appleby Bros., Southwark.

For Castings.—The next stage in slag utilization is the endeavour which has at various times been made to run the liquid slag as it flows in a stream from the furnace, into moulds; or, in other words, making slag castings. Such an idea at first sight would seem natural enough. Here, it may be said, is a material flowing to waste, in a liquid state, capable of being run into moulds, and of taking impressions almost equal to those of cast-iron. The castings also, when successfully made, are exceedingly durable, and even beautiful to look at. So alluring has been the idea of casting, that during the last 50 years the Patent Office has recorded almost annually the attempts of some inventor impressed with the notion that he could treat this treacherous fluid successfully. To describe these various schemes, or to give even an outline of them, would occupy too much space, but the following remarks will afford a general idea of the difficulties.

The high temperature at which the slag leaves the furnace has been before noticed—namely, about 3000° F. (1727° C.), but, when it is brought into contact with anything cold, in the shape of a mould, it readily parts with its heat, and, in so doing, suddenly contracts. The surface contracting, becomes filled with fine cracks or flaws; so much is this the case that, if allowed to assume entire consolidation in the moulds, these cracks will be found to penetrate completely through the casting, and upon exposure to the air the casting falls to pieces. This is the more vexing as, when slag is run into a large mass —say into a pit of sand 8 or 10 ft. deep, and containing 30 to 40 tons—there is such an enormous amount of heat accumulated that it becomes self-annealing, the outside of the mass is kept at a high temperature, and, if allowed to remain until cool, not a flaw will be found, and the slag becomes so tough and hard that it may be quarried in the same way as granite or whinstone, and used for street-paving.

For Paving-blocks.—There is, however, one exception to the numerous failures in slag-casting. It is known as Woodward's patent, and although there is absolutely nothing new in the process, still, through the perseverance of Dobbs, the late manager and engineer for the furnaces of T. Vaughan and Co., an amount of success has been arrived at sufficient to enable the company which works the process to pay a fair dividend. The success has been eminently a practical one, and appears to rest mainly upon 2 points:—Firstly, in the quickness with which the castings are removed from the moulds and placed in the annealing ovens, where the temperature is constantly kept up nearly as high as the melting-point of slag, the heat, after the ovens are full, being so gradually lowered that the outside of the casting cools at the same rate as the inside; the contraction is thus equalized throughout, strains upon the outside are avoided, and the fine surface cracks do not penetrate much below the skin. And secondly, upon the fact that only solid rectangular blocks, with a certain amount of bulk in them, are attempted.

At the works of the Tees Scoria Paving-block Co., blocks are made by running the liquid slag into a series of open-topped moulds. The moulds are of cast iron, and are held by one end upon the periphery of a horizontal wheel or table. The wheel is suspended by tie-rods upon a central pillar. The moulds, when being filled up, are brought in succession under the slag-runner by the man in attendance, who watches until the mould is full. When the slag has become consolidated in the moulds, a catch-hook is knocked up, the moulds fall to pieces, and the bricks drop to the ground. When they come out of these moulds, although consolidated, they are still in a sort of half-molten state, and are immediately removed into annealing ovens, which are always kept at a high temperature, so that the blocks receive no chill. The ovens are of small size, and when full

are sealed up, and allowed to cool down by themselves. There are about 70 moulds upon each machine, and the hotter these are kept the better; whilst, to prevent chilling of the molten slag as it runs into the moulds, they receive a thick coating or washing of chalk or lime after each casting, the lime acting as a non-conductor as well as assisting the block more readily to drop out of the mould. Thus the casting is not allowed to remain in contact with anything which can extract its initial heat, so as to produce unequal cooling; and, as before stated, the whole success has been eminently a practical one, and reflects great credit upon those who have so patiently worked it out. Large quantities of these bricks or paving-blocks are used in the North of England for crossings, stables, yards, and streets, possessing durability, uniformity, and good general appearance when well set. From a series of tests recently made against a crushing strain, some of these blocks carried a weight equal to the hardest granite.

For Bottle-glass.—The next successful process for dealing with molten slag is Bashley Britten's. He converts it, by a kind of compound process, into glass for bottle-making, and for many purposes where a pure white glass is not essential. The slag is taken from the blast furnace in large ladles upon wheels, in quantities of about 500 lb. In this state it can be conveyed a considerable distance to the glass works, where it is poured into a Siemens regenerative gas-furnace, known as the "continuous melting tank furnace," arranged to work with gas made by a Wilson's gas producer, and considered to be a great improvement upon the furnace employed at the slag-glass works at Finedon. The material is fused and amalgamated in a melting-tank. The fluid metal, becoming fused, flows through a bridge into a secondary chamber called the gathering basin. The glass is withdrawn from this basin through a series of holes by the workmen, and fashioned into bottles, or other useful articles, in the usual way. By this arrangement the work of charging and withdrawing the liquid glass is continuous and proceeds uninterruptedly. The consumption of coal per ton of slag-glass should not exceed 10 to 12 cwt. With each charge of molten slag into the melting-tank, alkalies and sand, and colouring or decolorizing material, are added in proportion depending on the quality, colour, and composition of the glass required.

So far, the only slag operated upon is that produced from the Finedon furnaces in Northamptonshire, a very siliceous slag, the analysis of which is as follows:—

Silica			38·00
Alumina			14·87
Iron protoxide			0·36
Manganese protoxide			0·39
Lime			38·19
Magnesia			1·90
Titanic acid			1·00
Potash			1·58
Calcium 1·55 Sulphur 1·24	as	Calcium sulphide	2·79
			99·03

To make bottle-glass equal in quality and appearance to French champagne and claret glass, about 50 per cent. of slag may be used; for plate-glass, the same proportion, or rather less of slag; but for glass for heavier articles, a much larger percentage can be adopted. Bottles made from slag-glass are stronger than those manufactured in the ordinary way from the usual materials, and will stand 320 to 350 lb. per sq. in.; half-bottles (pints), 420 to 450 lb. per sq. in. Slag-glass, owing to its toughness, is especially suitable for manufacturing into tiles, cisterns, plates, slates, &c., for which glass is not now employed. The chief points of merit claimed for the process are the utilization of a waste product, economizing the heat of the molten slag, and converting it, with additional materials, into good glass, quicker, and at less cost, than by the processes generally employed.

Slag-shingle.—In 1871, the waste land for the deposit of slag at the Tees

Iron Works being filled up, and the works of the Tees Conservancy having temporarily been brought to a standstill, it became of serious moment to know what was to be done with the slag.

The cost of cooling it, and putting it on board barges for taking out and tipping it into the sea, was so heavy, that it was suggested the slag should be prepared in such a form that it could be tipped into the barges in the same way as coal is done upon the Tyne and other places. To meet these requirements, several schemes were proposed and tried; amongst the first (and only successful one) is the horizontal rotary slag-cooling table designed by Wood, and which, with little alteration, continues to work up to the present time. The machine upon which the slag falls revolves very slowly, and is about 16 ft. in diameter. The top of this table is formed by a series of slabs; these receiving or cooling plates, or slabs, are about 2 ft. in width, each forming a segment of the circle. These plates are kept cool by having a zig-zag wrought-iron pipe cast in them, through which water circulates, being fed from a centre globe; the water, after passing through 2 plates, flows into the basin under the table. These water plates are bolted down in such a way as to be able freely to expand and contract. The liquid slag, as it flows from the usual runner, spreads itself upon the moving table into a broad band of slag, varying in thickness from $\frac{1}{2}$ in. to $\frac{3}{4}$ in., depending upon the quantity and fluidity of the slag. From the point where the table receives the molten slag a distance is traversed of about 10 or 12 ft., to allow the slag to consolidate; after which, water from a jet is made to flow freely upon the surface of the hot slag until it reaches a set of scrapers, when, having become nearly cool, it is pushed off into iron waggons below. When the slag reaches the scrapers, it has become somewhat brittle, and readily parts from the table, and slides off in large flat pieces. When perfectly cold, it is tipped from the waggons, and falls into small-sized pieces, called "slag-shingle." The produce of this machine has found such ready sale that it has been kept going almost constantly ever since it started, and about 200,000 tons have been sold, chiefly for making concrete. In place of paying 6*d.* per ton to get rid of the slag, it has realized about 1*s.* 3*d.* per ton.

The large concrete blocks, each weighing about 230 tons, constructed by Fowler, for dropping into the sea to form the head of the Tees breakwater, are chiefly composed of this material, and several heavy foundations for engines, drainage work, building, &c., in the district, have been executed with it.

Slag-sand.—The next great step in advance, and which laid the foundation for several processes hereinafter mentioned, was the reduction of the molten slag, as it flows from the furnace, into a soft spongy kind of sand, by a machine known as Wood's slag-sand machine. In principle it is the reverse of the slag-shingle machine, inasmuch as, instead of the wheel being horizontal and the slag running upon a dry table, the slag flows into a wheel placed upon its edge, and falls into a bath of water, varying in depth from 18 to 24 in. The wheel or drum is of wrought-iron, and about 14 ft. in diameter. It is fixed and carried on curved arms. The arms are curved to allow, in the first place, the slag runner or spout to enter the wheel; and secondly, to make room for the sand-receiving spout on the opposite side at the top. The wheel makes about 5 revolutions per minute, and the water contained inside is partly carried up by the elevators, and in falling causes a constant rush of water to the bottom. Perforated screens, or elevators, are arranged to screen the slag from the water, and lift it to the top of the machine, where it drops upon the sand-receiving spout, and thence slides in a constant stream into wooden waggons. The spout is also perforated, to allow any water which has been carried over with the sand to return into the machine. The perforated buckets have another important function to perform,

viz., that of agitating the water. The water, in rushing to the bottom, meeting these obstructions, rolls over in a violent manner, and into this agitated water the liquid slag flows just as it comes from the furnace. The united action of the agitated water and the formation of steam, scatters, as it were, the molten slag in the water into the material called slag-sand. The wear and tear of this machine is very light, there being no working parts coming in contact with the sand or the heat. The heat, being taken up by the water, is thrown off in the shape of steam, which comes away in large volumes. Grey slag takes up about 20 per cent. of its own weight in water. The total cost of this sand in railway trucks is about 6*d.* per ton.

On the Continent, a kind of slag-sand has been made—prior to the adoption of the process just mentioned—by running the slag into tanks full of water, and elevating the sand by chain buckets into waggons; but the apparatus is very imperfect, and will only work slag made from forge iron, known as black slag.

The application of slag-sand, in so cheap a form, to the useful arts, naturally followed the production, and after numerous experiments, extending over many months, it was decided to establish separate works in close proximity to the furnaces, where, under Wood's own direction, various processes could be developed; and in 1876 the first manufactory of the kind was started. In Georgemarienhutte, in Hanover, under the direction of Luurnan, a process of brickmaking was initiated a few months previously.

The remarkable setting properties of slag in a state of subdivision has attracted the attention of scientific men for years, and many schemes for producing artificial stone, cement, &c., have been tried; but, in consequence chiefly of the cost of disintegration, no results were obtained with commercial success.

John Gjers, of Middlesbrough, about 15 years since, produced a coarse kind of slag-sand, which, after grinding under edge-runners, was used extensively for some little time upon the pig-beds; but it had to be abandoned, because it consolidated too much, causing violent explosions (technically termed "boils"), from the steam from the damp sand being unable to escape when the metal was run from the furnace in pigs.

For Cement.—Up to the time when the Cleveland Slag Works was started, there was not a single instance of slag utilization in this country—otherwise than for road-making or for river-work—commercially carried on. Before proceeding to describe the various manufactures produced at the Cleveland Slag Works at Middlesbrough, it is necessary to draw attention to the chemical nature of the material operated upon. The following analysis gives a good general idea of the chief slags produced in the United Kingdom:—

	Cleveland.	Hematite Bessemer.	Dowlais.	Dudley.
Lime	32·61	50·55	30·47	35·68
Silica	36·50	30·50	43·07	38·76
Alumina	22·95	15·00	14·85	14·48
Iron protoxide	0·06	0·45	2·53	1·14
Manganese protoxide	0·32	0·10	1·37	0·23
Magnesia	5·83	2·00	5·87	6·84
Potash	0·59	0·40	1·84	1·11
Soda	0·31	0·20	..	..
Sulphur	1·73	1·50	0·89	0·98
Phosphoric acid	..	..	..	..
	100·90	100·70	100·89	99·26
Less oxygen of the lime combined with sulphur	0·86	0·75	0·44	..
	100·04	99·95	100·45	..

A table of comparative analysis is given on the next page, for easy reference. It will be noticed that 3 most important component parts of these slags are silica, alumina, and lime, forming, as they do, about 90 per cent. of the whole. The latter of these, however, chiefly exist as silicates; if to

these, caustic lime be added, they are acted upon, water of combination or crystallization being taken up; and if the material be kept damp and exposed to the air, hardening or induration is carried on for months.

making concrete for heavy foundations and the setting properties and strength of this combination have upon examination been fully confirmed. Again, having to erect a row of columns for a large roof upon the bed of an old iron-

	Slag.				Portland Cement.	Slag Concrete Bricks.	Slag Cement.	Gypsum.	Puzzolanas.
	Hematite Bessemer.	Cleveland.	Dowlais.	Dudley.					
Lime	50·55	32·68	30·47	35·68	60·88	29·90	22·90	32·32	8·00
Silica	30·50	36·50	43·07	38·76	23·16	25·15	21·60	0·35	..
Alumina	15·00	22·95	14·85	14·48	7·68	21·80	19·85	..	..
Iron protoxide	0·45	0·06	2·53	1·18	..	1·44	4·00	..	..
Manganese protoxide	0·10	0·31	1·37	0·23	..	0·26	0·21	..	..
Iron peroxide	..	..	..	..	3·00	1·66	8·80	..	12 to 15
Magnesia	2·00	5·83	5·87	6·84	1·01	5·10	4·36	..	..
Potash	0·40	0·59	1·84	1·11	0·72	0·53	0·50	..	..
Soda	0·20	0·37	..	..	0·31	0·36	0·32	..	..
Sulphur	1·50	1·73	0·89	0·98	0·05	1·00	1·19	..	..
Sulphuric acid	..	..	..	..	2·60	1·25	1·54	46·18	..
Phosphoric acid	..	..	..	..	0·08	0·01	0·02	..	..
Carbonic acid	..	..	..	..	..	2·60	3·00	..	..
Water (of crystallization)	..	..	..	..	0·77	9·50	12·00	21·00	..

If caustic lime be added to slags poor in lime, so as to bring this element up to 55 or 60 per cent., it will be seen at once how closely it will resemble the analysis of Portland cement, the composition of which is as follows:—Lime, 60 per cent.; silica, 24; alumina, 8; iron oxide, 4. German Portland cement is sometimes made with as low as 55 per cent. of lime, whilst Roman cement has often only 50 per cent. of lime; but these will generally be found to contain oxides of iron in an increased proportion.

The remarkable hardening effect of oxides of iron in conjunction with lime, silica, and alumina, is well known, and is well exemplified in the Italian puzzolanas, where, in several of the best qualities, the lime is actually as low as 8 per cent., whilst the oxides of iron run up to 12 or 15 per cent. The hardening effect of iron oxides induced Wood, prior to the development of the slag industries, to employ the dust from the iron-stone clamps in place of sand, when

stone clamp, the floor of which had been accumulating for several years, it was found to be so extremely hard that Wood simply levelled the bed down, and set the columns directly upon it. These, after many years, show not the slightest signs of settlement, although the ground underneath had been made up from ships' ballast.

It appears an absolute necessity for obtaining good results, that the ferruginous material should be calcined or roasted, the effect of which is to drive off the carbonic acid and water; the re-absorption of the water, which unites in chemical combination with the material, afterwards assists in hardening.

Slag-cement.—The next product to be described is the manufacture of what is called slag-cement. The word cement has sometimes been objected to in connection with this material, because it is generally manufactured in a wet state, and must be used within a few hours of its being made. Upon this point Wood expresses no opinion, simply mentioning

the fact that, in point of strength, he finds little difference whether the materials are ground together in a dry or in a wet state. The cost of production, however, is as nearly as possible 4 to 1 in favour of the wet state. It is made by grinding under edge-runners, for about 1 hour (the finer the better), 70 per cent. of slag-sand, 15 of common lime, and 15 of iron oxides, calcined ironstone, or spent pyrites. Following is an analysis of this cement, lately made by Patterson and Stead :—

	Per cent.
Lime	22·90
Silica	21·60
Alumina	19·85
Iron protoxide	4·00
Manganese protoxide	0·21
Iron peroxide	8·80
Magnesia	4·36
Potash	0·50
Soda	0·32
Sulphur	1·19
Sulphuric acid	1·54
Phosphoric acid	0·02
Carbonic acid	3·00
Total water	12·00
	100·29
Less oxygen of the lime combined with sulphur	0·59
	99·70

Upon comparing this analysis with that of Portland cement and the puzzolanas already given, it will be seen that the various hardening ingredients exist in all.

The large quantity of water held in suspension in the slag-sand, is quite sufficient to make the mass in the mill into a semi-fluid state, but this water is mostly taken up in setting, as water of crystallization. It is therefore necessary that the cement should be used before setting takes place. This cement is usually employed for making concrete, by mixing 1 part of the cement to 5 of slag-shingle. The shingle is made by the slag-shingle machine before described.

The shingle, before being used, is well wetted; and when the concrete is put into place, it is beaten lightly down in a soft state, until the water and cement begin to rise on the top; 2 days afterwards it has become sufficiently set to allow of the building-boards being taken down, and at the end of a week it will be fairly hard, and will go on hardening for months. It is perfectly hydraulic, and will harden under water. It will be seen by this that it requires a longer time to set than Portland cement, and is perhaps not quite so hard; but there is a remarkable toughness, which has surprised all those who have used it, and this toughness makes it valuable for heavy machinery foundations, &c.; and, when made in proximity to the furnaces, the cost of the cement will not exceed 6*s.* per ton, whilst concrete made of this cement and slag-shingle will cost only 5*s.* 6*d.* per cub. yd.

These prices are absolute figures of cost, that of the concrete being arrived at after having executed many hundred cub. yd. upon the Tees Iron Works, at the new railway station at Middlesbrough, and elsewhere. The Slag Works buildings, the walls of which are between 70 and 80 ft. high, are built entirely with it, the basement walls being 2½ ft. thick.

Whilst the underground walls of the Slag Works were being executed, they were twice immersed, through exceedingly high tides, with the result that this part of the building is the hardest of all; and to give an idea of the strength, Wood mentions that when it was necessary to cut 2 openings at different points through the basement walls, 3½ ft. wide and 6 ft. high, this employed 2 good workmen, with steel bars and sledge hammers, at least 4 days for each doorway. He knows of no material at a similar cost which can compete with it, and he is satisfied that it has only to be widely known to be more extensively used. Personally, where time can be given, he employs nothing else for all heavy foundations for rolling machinery, for which purposes, as a conglomerate or monolithic

mass, it is peculiarly adapted. Slags from the furnaces making Bessemer iron are better adapted for this cement even than those from the Cleveland ores.

Mention has been made of the necessity of keeping the products from slag-sand in a damp state for a length of time after manufacture, in order to give them time to harden, or, in other words, to allow the material to absorb or take up as much water as will chemically combine with the lime, silica, and alumina; but whether this water becomes water of crystallization, or water of hydration, or a combination of both, is not at all certain. Wood is, however, strongly impressed with the idea that water in a fixed state, more particularly in a compound state, plays by far a more important part in the setting of cements than is generally supposed; that the presence of water in a chemically combined state forms as much a constituent part of cement as does the lime, silica, and alumina, seems certain from the results of the analysis shown further on. For instance, if Portland cement be heated to redness, so as to evaporate the fixed water, the cement loses at once its strength, and becomes rotten. Again, with gypsum, where the water of crystallization amounts to more than $\frac{1}{5}$ of its bulk; if this is driven off at a red heat, we have little better than a powder left. And it seems clear that the quicker this crystallization takes place, the quicker is the setting; and, on the contrary, as in the slag cements and the brick, the slower the water is in becoming fixed, the slower is the hardening; thus showing the necessity of keeping them damp during the process.

At Wood's request, Patterson and Stead made many analyses with the object of testing this point. Samples of Portland and Roman cements were mixed with water in the usual way, some specimens being supplied by the cement manufacturers themselves, as vast pieces, from their works, and had consequently been under water for terious periods. These were all reduced to powder, and carefully dried by keeping them for several hours at a temperature of 212° F. (100° C.), so as to evaporate every particle of free mechanically-mixed water. A very careful determination of the chemically-combined water was then made, with the following interesting results:—

Combined Water.

4 days in water.		6 days in water.	
Portland.	Roman.	Portland.	Roman.
5·75%	5·25%	6·8%	6·78%

7 days in water.		
Portland.	Slag cement.	Slag brick.
7·75%	10·50%	5·70%

From this it seems certain that the hardening follows closely in proportion the quantity of water which becomes chemically combined, and that the slag-cement undergoes a similar change to that which takes place in Portland or Roman cements. That other chemical changes occur there seems also to be no doubt, and with Portland, or Roman, or slag cement—time being left out of the question—the same chemical changes apparently ensue.

Ransome, the well-known inventor of artificial stone, has recently taken out a patent for mixing the slag-sand in its wet state with chalk, and then burning the whole together in a cement kiln into clinker, after which he grinds it down in the same way as Portland cement. The results given are remarkable, exceeding Portland cement in strength by nearly 30 per cent.

Reid made some experiments on the application of slag to the manufacture of Portland cement, and could not get very satisfactory results; but that was before Wood's granulated slag was to be had. He found the greatest difficulty with the sulphur. He got in his slag about 1¼ per cent. of calcium sulphide, which would amount to about 2·84 per cent. of lime sulphide in the cement when finished, an amount which made the cement very unreliable. He found also that, in working up the slag with the lime, it was very difficult to incorporate the 2 thoroughly; but it was very possible that Wood's granulated slag,

which was very finely divided, might be more easily mixed with lime. The amount of sulphur usually contained in Portland cement, according to Grant, is nearly 2 per cent. If you were to make cement from slag already containing 12 per cent. of sulphur, you would get 4 per cent. of lime sulphate in it, which would render it unreliable. This process was patented by Bodmer in 1866; the specification stated that the invention consisted in the manufacture of a cement by mixing together slag cinder or scoria, whether naturally or artificially produced from furnaces, with a certain proportion of lime or calcareous matter, and with or without alumina. Egleston has referred to blast-furnace slags being used for various things, and amongst others for the manufacture of cements. He said that the possibility of having them in the form of granulated slag, reduced the price of the pulverized material to such a figure that, in certain parts of Germany, an artificial cement equal in every respect to the best Portland was manufactured at a large profit.

For Mortar.—Mortar for building purposes is another material supplied at the Cleveland Slag Works. It is simply made by grinding the slag-sand with about 6 per cent. of slaked lime in an ordinary mortar-mill, and (if ground fine) it makes a far better mortar than is generally employed by builders. Two years ago there was a very large demand for this material in Middlesbrough. There is only one objection made to it, viz., that it sets too quickly. Mortar supplied on the Saturday, left unused, would be worthless on the Monday. As with the other slag products, its remarkable strength and cheapness combined make it much liked by those who, in close proximity to the works, can obtain it freshly made.

For Bricks.—At the Cleveland Slag Works the most important production, and the one which consumes by far the greatest quantity of slag, is that of concrete-bricks, known in the market as slag-bricks. These are made from the sand produced by the slag-sand machine before described. The sand is dropped from the railway wagons into hoppers, or depôts, at the works, whence it is filled into large barrows, taken up a hoist to the top of the building, and tipped into a hopper, which supplies a measuring apparatus. Here it is mixed with a certain quantity of selenitic lime (General Scott's patent), with an addition of iron oxides; it then passes into the brick-press hereinafter to be described. The bricks are taken off the presses by girls, placed upon spring-barrows carrying 50 bricks each, and removed to air-hardening sheds; here they remain a week or 10 days, after which they are stacked in the air to further harden, and at the expiration of 5 or 6 weeks they are ready for the market. Here is the curious anomaly of bricks being made without burning, and of a wet season being favourable to the hardening process. The bricks thus produced are very tough; they do not split when a nail is driven into them, and are easily cut; they do not break in transit, and the frost has no effect upon them. According to a certificate received from Kirkaldy's testing-works, some of these bricks, taken from stock 3 years old, carried a pressure of 21 tons before crushing, whilst others only 4 months old crushed with 9 tons pressure; showing not only great toughness, but also that they greatly improve by age.

There are now 2 machines fully employed, making about 130,000 bricks weekly, consuming 250 tons of slag-sand and 30 tons of selenitic lime and oxides.

The preparation of this selenitic lime forms a necessary branch of the business. It is made in the following manner:—

80 per cent. of unslaked common lime.
10 per cent. of raw gypsum.
10 per cent. of iron oxides calcined.

These are all ground together, under edge-runners, into a fine dry powder. The composition is then passed through a fine sieve, 24 meshes to the inch, and is ready for the brick-press. To each

1000 of bricks, 6 cwt. of this lime is used; no water is added, sufficient being held in suspension in the slag-sand to thoroughly moisten the lime; in fact, it is no uncommon thing to find flowing from the brick-press a stream of water which has been squeezed out of the sand. The loss of bricks in manufacture is very small; in fact, after the bricks are once upon the barrows, the waste is not more than $1\frac{1}{2}$ per cent. At the present rate of production, there is a consumption of slag for this one article alone of about 14,000 tons per annum. The weight of these bricks is about 30 per cent. lighter than ordinary red ones —9 in. by $4\frac{1}{2}$ in. by $2\frac{1}{2}$ in.—weighing only $2\frac{1}{4}$ tons per 1000. Another interesting feature in connection with these bricks is the economy in manufacture, which—including all materials, labour, wear and tear of machinery, superintendence, power, and everything except interest on capital—does not exceed 10*s.* 6*d.* per 1000. The following is an analysis of these bricks, made by Patterson and Stead, and will be found worthy of notice, showing the hardening properties contained, the composition comparing favourably with the cements previously mentioned:—

	Per cent.
Lime	29·90
Silica	25·15
Alumina	21·80
Iron protoxide	1·44
Manganese protoxide	0·26
Iron peroxide	1·66
Magnesia	5·10
Potash	0·53
Soda	0·36
Sulphur	1·00
Sulphuric acid	1·25
Phosphoric acid	0·01
Carbonic acid	2·60
Total water	9·50
	100·56
Less oxygen of the lime combined with sulphur	0·50
	100·06

As before mentioned, the lime used for making bricks is selenitized, the following being the analysis of the raw gypsum employed in the process:—

	Per cent.	
Sulphuric acid	46·18	Lime sulphate
Lime	32·32	
Silica	0·35	
Water at 100 per cent.	Nil	
Ditto given off at red heat, being water of crystallization	21·00	
	99·85	

The process of brick-making, as now carried on, is extremely simple, and, as already shown, inexpensive; but it was here that the greatest difficulties were met with. There was no machinery to be purchased that could work the slag-sand into bricks, in the state in which it arrived from the blast furnaces. In the earlier attempts, the sand had to be prepared in a fine state, the result being a superior class of bricks, but at a cost so great as to exclude them from the market. Wood had therefore to design and construct brick-presses and other machinery that could work the sand, as it came from the slag-sand machines, directly into bricks. The success of this machinery at once rescued the Cleveland Slag Co. from an early collapse, but not before a large amount of money had been spent and some 2 years wasted.

In designing the press, the following points had to be kept in view, viz.: unusual depth of brick moulds, as the sand (being spongy) is exceedingly compressible; great pressure, in order to consolidate the slag; as well as great care in mixing the lime in fixed proportions to the sand—too much lime tending to burst the bricks, whilst too little seriously affects the hardening.

For Artificial Stone.—One other manufacture from slag is carried on at the Cleveland Slag Works, which, although it does not consume much, is still of interest, viz., artificial

stone. It is moulded into chimney-pieces, window-heads and sills, balustrading, wall coping, and other ornamental work for builders, as well as for paving for footpaths, stables, &c. The stone is composed of 2½ parts finely-pulverized slag, and 2½ of ground fire-brick, to 1 of Portland cement; the mixture is run into moulds, and sets quickly, the articles being ready for the market in 5 or 6 days.

A sort of concrete brick has been made by the Moss Bay Iron Co., Workington, from hematite Bessemer slag. These bricks have been made by a process differing entirely from the system adopted by Wood at Middlesbrough. The slag employed at Moss Bay is pulverized from the cold solid mass under heavy edge-runners, which crush the material into fine dusty shingle; it is then lifted by elevators into French burr-stones, and ground down as fine as sand. From the stones it passes through a worm conveyer to a brick-press, during which about 25 per cent. of common river-sand is added, with sufficient water to thoroughly damp it, without any addition of lime; again showing, in a remarkable degree, the extraordinary setting nature of the slag after the chemical combination with the water and exposure to the air have taken place. These bricks are taken from the press and placed under cover for a few days, when they are put out in the open air to harden. They are of excellent shape, grey colour, and become exceedingly hard. Large quantities have been employed in building the Moss Bay Steel Works, and appear to be standing remarkably well. The cost, however, is very heavy, owing to the difficulty of preparing the slag, and the wear and tear of the machinery; the excessive weight also precluding the sale at any great distance from the works. The large amount of lime, combined with the silica and alumina in the Bessemer slag, quite accounts for the setting properties. The bricks continue to harden for years, and appear to arrive at a kind of crystalline fracture, which damp greatly accelerates.

Slag-wool.—One more application of blast-furnace slag is the manufacture of slag-wool, or silicate cotton, so called from its resemblance to cotton-wool. The first attempt at this manufacture was in 1840, by Edward Parry, in Wales, and a large quantity was made; but no effort appears to have been made to confine the wool after production; consequently it floated about the works with the slightest breeze, and became so injurious to the men that the process had to be abandoned. About 4 years ago, Krupp of Essen, and a little later, Lurman of Georgmarienhutte in Hanover, both supplied a great deal to the market; but the precise methods of manufacture never transpired, having been kept a secret at the works; and until 2 years ago the wool had never been successfully made in this country.

As carried out by Wood at the Tees Iron Works, the process is exceedingly simple. A jet of steam is made to strike upon the stream of molten slag as it flows from the usual spout into the slag waggons or bogies. The steam scatters the slag into shot. As each shot leaves the molten stream, it draws out a fine thread, just in the same way as when you touch treacle lightly with the finger—if you lift it up you will see a fine thread attached. The consistency of molten slag is not unlike treacle; each shot makes a fine thread which, losing its heat, becomes set like glass. The shot being heavy, drops to the ground, but the thread is sucked into a large tube by an induced current of air caused by the steam jets, and the wool is discharged into a large chamber. The finer qualities float about and settle near the outside, whilst the heavier or larger fibres lie chiefly in the centre of the chamber. After each blowing, the chamber presents a most remarkable and curious as well as a beautiful appearance. The wool is of snow-white colour, and attaches itself to the sides and roof, or to anything which it can touch, in the same manner as a light fall of snow does in calm weather upon every tiny twig of a leafless tree. The wool is taken up daily with forks, and

put into bags for sending away. It is principally used for covering boilers or steam-pipes, for which purpose it is peculiarly adapted, as being a splendid non-conductor of heat, and incombustible. About 4 tons of this wool is produced per week, and as only ¼ cwt. is made from each ton of molten slag operated upon, the process is not a very rapid one.

Repeated bursting of hot-water pipes encased in slag-wool induced Professor T. Egleston to examine into the cause. The results he obtained are set forth in the following abstract from his paper on the subject (*Trans. Amer. Soc. Civ. Engs.*, cclix. 253-61):—

Slag transformed into wool does not differ in any respect from slag in a solid condition, except that its fibres become interwoven. It occupies, when not compressed, a maximum volume for a minimum weight, and thus retains a very large quantity of air. This is its only value: it is the air and not the slag which is required. The only value of the slag is its capability of holding this air when it is not compressed; when it is compressed, it has very little more value than slag in its solid form. This compression may be caused by the sagging of the pipes on it, if only the envelope and not the pipe is supported, or by its becoming soaked with water, when it mats together, water takes the place of the air, and it ceases to be a non-conductor of any value. Its great value is in its very fine fibres, but it is precisely this quality of fine division which makes it most dangerous, for in this condition it is most easily attacked by organic acids, alkalies, or moisture, which not only decompose it, but render the pipes liable to attack. Even the commencement of decomposition causes it to sag and settle.

It would seem, therefore, that mineral wool, if made from slags containing sulphur, is, under certain conditions, a dangerous material. In one case of explosion, the moisture undoubtedly came from defective joints, which are likely to belong to any other system. In the other and far more dangerous one, this moisture was that of condensation; and as it was not expected, every precaution having been taken against it, it is by far the more dangerous one, as it would not be looked for, while every joint would from time to time be visited. In any system, moisture is likely to come from rain or snow leaking through the envelope, where the pipes are exposed above ground in the open air, or, when they are below ground, from drainage water, and, in both cases, from condensation, due to sudden cooling or too sudden heating of the pipes. The effects produced are likely to be all the greater in intensity as the pipes are hotter, this facilitating the liberation of the sulphuric acid, which produces a further decomposition of the slag, and keeps setting free new portions of acid to further decompose the slag and attack the iron. The moment the silica commences to assume the gelatinous condition, the other constituents of the slag are set free to attack the pipes, and unless the leakage is found and stopped, an accident is sure to happen. It seems, therefore, a wise precaution, when this substance is used, to employ it only where leakage is not likely to occur or moisture to collect, and to carry the whole system above ground, under cover; or, when it is necessary to carry it below the surface, to have all parts easily accessible, so that it may be carefully examined from time to time. Beneath the ground, where it cannot be examined, it becomes a real element of danger. Kept free from moisture, mineral wool is one of the best and cheapest materials that can be used for covering steam pipes. To employ it successfully, it must not become packed, for then it loses its non-conductive power. When it becomes moist, it packs; and if this moisture and packing are continuous, the slag is attacked, liberating its dangerous elements to act on and weaken the pipes.

For Insulating.—Buttgenbach, the well-known metallurgist, gives the following method for the utilization of blast-furnace cinder as an insulator for steam-pipes, &c.:—Mix 150 parts cinder-

dust, 35 of fine coal-dust, 250 of fire-clay, and 300 of flue-dust, with 10 of cows' hair; add 600 parts water into which 10 to 15 of raw sulphuric acid have been poured, and make a stiff dough of the whole. This is thrown in small amounts upon the warmed pipe, hardening rapidly. Upon this rough coat a second, third, &c., is laid, according to the thickness which is to be used. By the action of sulphuric acid gypsum is formed, and the silica, rendered free, hardens. The mass becomes as hard as porcelain, and is still porous. It adheres firmly and never cracks. Buttgenbach states that he has tested its merits by 10 years' use, and has found it to meet all requirements.

For Manure.—A material containing so much lime, silica, alumina, sulphur, and magnesia, in a condition like the white soft slag sand, suggested its application as a fertilizer for some kinds of land. Three years ago it was brought before the Royal Agricultural Society, and Dr. Voelcker reported that the result of his examination showed that it might be usefully employed upon moorland and peaty soils as a cheap and effective substitute for lime. Since this report was made, many hundreds of tons have been sold for this purpose, and although there was only 32 per cent. of lime in the slag supplied, the results have been very satisfactory, particularly on land growing potatoes. Had it been Bessemer slag, containing 40 to 50 per cent. of lime, there cannot be a doubt that the results would have been still more satisfactory; and Wood feels sure that it must in some localities find a large outlet for this purpose.

The successful attempts made in recent years, to remove the phosphorus from iron in the course of manufacture by the basic process, have attracted the attention of chemists to the possibility of recovering the valuable manure, phosphoric acid, from the slag. A patent has been recently obtained by Thomas and Twynam for the manufacture of phosphoric acid and phosphates from slag, especially adapted to their recovery from slags produced in the basic Bessemer and Siemens processes. The slag is first finely ground, and the particles of iron are picked out by means of magnets; it is then treated with sufficient hydrochloric acid, either in aqueous solution or in vapour, to dissolve out the phosphoric acid, and part of the iron oxides. The powdered slag may first be roasted in a calciner, to oxidize the ferrous oxide. If sufficient ferric acid be not present in the solution to combine with all the phosphoric acid, it will be necessary either to add some ferric oxide or puddlers' slag (which should preferably have been first roasted), or to oxidize any ferrous oxide present, either by chlorine gas or by the addition of manganese binoxide (in which latter case there must be sufficient free acid in the solution to cause the decomposition of the manganese binoxide and set free chlorine), or the ferrous oxide may be oxidized by other well-known means. The solution is then run off from any insoluble residue, and sufficient lime or (preferably) chalk is added to cause precipitation of ferric phosphate (magnesian limestone may be used in place of ordinary limestone for this purpose, the magnesia dissolved being afterwards precipitated by lime). The precipitation of the ferric phosphate may be effected in the cold, keeping the solution well agitated; but a gentle heat causes the precipitate to settle down better. When the precipitation is complete, the ferric phosphate is separated from the solution by filtration, and washed to free it from calcic chloride. The precipitate is then dried, so as to drive off all its water; and digested with a considerable excess of sulphuric acid, so as to decompose it into phosphoric acid and iron sulphate, which latter is insoluble in the excess of sulphuric acid employed. Ordinary chamber acid is able to effect this decomposition, but a stronger acid, such as is obtained when using a Glover tower, is better adapted for the purpose. The ferric phosphate should be kept well agitated in the liquid, which may be gently heated to facilitate the decomposition. When the ferric phosphate is considered

to be completely decomposed, the insoluble ferric sulphate is separated from the solution containing the phosphoric acid and excess of sulphuric acid by means of a filter-press. The filtrate will be found to contain nearly all the phosphoric acid in a free state, together with the excess of sulphuric acid, from which it may be separated by the aid of heat; the sulphuric acid being driven off and condensed, leaving the phosphoric acid practically pure, or the solution containing the mixed acids may be used in place of ordinary sulphuric acid for making super-phosphate of lime. The iron sulphate precipitate after being washed with sulphuric acid may be decomposed by heat into ferric oxide and fuming sulphuric acid, or it may be mixed with salt and heated to form sodic sulphate. In some cases, when there is no lime in the slag employed (as when treating puddlers' cinder), the phosphoric acid is thrown down as a mixed ferrous and ferric phosphate by means of lime without previous oxidation, and is then dried and treated in the same way as ferric phosphate.

For Casting-beds.—In the Siegen district, Belgium, granulated slag is used for casting-beds, and gives clean pigs, preferred by the puddlers even to those cast in iron moulds.

The Cleveland Slag Works.—In works where so many special manufactures have been developed, the arrangement of the building—the design, position, and working of the machinery at present used—must necessarily have been arrived at only by hard-earned experience. The building is constructed of slag-cement concrete throughout; the main building has 4 floors, the size of which is 46 ft. by 33 ft., whilst the slag-sand stores, gantry, engine-house, lime-house, &c., occupy 97 ft. by 47 ft. The slag-sand is brought from the blast furnaces in large wooden railway trucks, holding between 7 and 8 tons each, and is run up an incline by the locomotive into a gantry. The bottom doors of the trucks are opened, and the slag-sand is dropped or emptied into hoppers below. These hoppers are capable of holding about 600 tons of slag-sand, or storage enough for 1 week for 3 machines, and should be kept constantly filled. From these hoppers it is drawn into large wheel-barrows, and is taken up by a double-acting hoist to the top of the building. This hoist is driven from the main shafting in the mill, and is worked by 2 belts, one crossed, the other open, for the purpose of reversing the cages. The cages can be made to stop themselves at any floor, and have a self-acting brake to prevent any movement of the cages after the straps are thrown off, the action being most simple and effectual.

The sand-barrows are taken from the hoist at the top of the building, through a passage, and tipped into the hopper which supplies the brick-presses. Selenitic lime is fed into a small hopper, by hand, from a chamber or floor above. At the bottom of these sand and lime hoppers are the measuring apparatus, which accurately measure both the lime and the sand in the proportions necessary. From the measuring drums the material falls upon sifting and mixing apparatus, from which it falls through the floor into the brick-press. This press has been designed especially for the purpose, and has many new points. It is of immense strength. The pressure is obtained by 2 cast-steel cams, which are fixed upon a forged steel shaft $7\frac{1}{4}$ in. in diameter; this shaft, resting on bearings between 2 strong frames, is put in motion by very powerful double-geared spur-wheels, the first motion shaft having a heavy fly-wheel upon it to steady and equalize the pull upon the strap. The pressure cams act against rollers fixed upon 2 steel cylinders or rams. These rams transmit the pressure to the moulds under the table. The table is circular, and contains 6 pairs of moulds, so that 4 bricks are pressed at one time, the table remaining stationary during the operation. At the same time the bricks are being pressed, 2 other pairs of moulds are being filled up with material, whilst the other 2 pairs are delivering up the 4 bricks already pressed at the previous

revolution of the cam shaft. The bricks are pushed out of the mould by smaller pistons, which are acted upon by separate cams. The moulds are lined with changeable steel plates $\frac{3}{16}$ in. thick, and the sand and lime are fed into 2 pug-mills. These pug-mills are fitted with 6 knives each, so as the more thoroughly to mix and chop the spongy slag with the lime. The table is shifted round by a kind of ratchet motion. Immediately above the pressure-cylinders are 2 pressure-stops, which are held down by the heavy-weighted levers. These levers, therefore, receive the whole pressure put upon the bricks; and in case there should be too much sand getting into the moulds, they simply lift up and relieve the strain. The weights can be weighted at option, and thus form an exact gauge of the pressure upon the bricks. The moulds are generally filled so as just to lift the levers in ordinary work. The filling is easily regulated by the set of the knives on the pug-shafts, which press the material into the mould, and one side of the pug-mill cylinder is made to open, so that the knives are accessible at any moment.

The pug-mills are filled by means of measuring and mixing apparatus placed on the floor immediately above the brick-press. The mixing and measuring apparatus is very simple and efficient, and works without trouble. The slag-sand is tipped into a hopper by large barrows, which are lifted up by a hoist. At the bottom of this hopper there is a revolving cylinder, with ribs cast upon it, which, revolving under the hopper, carries a certain thickness of sand, previously regulated to the requirements of the press. The slag then falls upon a sieve, which separates any large pieces in a solid state, and at the same time allows the sand to fall through the sieve like a shower. The lime is fed into a separate hopper, and is regulated by a feed-roller of smaller size; it passes down a shoot, which forms part of the slag-sand sieve, where it meets the shower of sand, falling together with it—thus getting thoroughly mixed. On the right side of the slag gantry and hoppers is the mill for preparing the selenitic lime. The lime, after being ground under edge-runners, is passed through a sifting apparatus, the wire of which has 24 meshes to the inch; it then falls into a hopper, is taken by barrows through a passage to the hoist, and lifted to the lime chamber before mentioned. In a line with this mill, and parallel with the slag gantry, are the stores for the lime, gypsum, and iron oxide; whilst behind the lime-house are the engine and boiler.

The hardening-sheds are 3 in number, and should be each about 100 ft. by 40 ft. The floor must be perfectly smooth and level, as an uneven floor spoils the bricks. The sheds should have plenty of ventilation, and require to be cool in summer. Great care is necessary in stacking these bricks; as they come off the barrows, they are placed on edge quite close together, and stacked 6 in height, and when once here in position, there is little or no loss afterwards.

SODIUM.—The salts of sodium are abundantly and universally distributed, the most common and familiar being the chloride—common salt; the nitrate, carbonate, and sulphate also form considerable geological deposits, and the silicate occurs in many minerals. The metal, like potassium, can be prepared by electrolysis, but less easily. A second method is by decomposing caustic soda with metallic iron at a white heat; and a third, which is that adopted on an industrial scale, consists in igniting a mixture of soda carbonate and charcoal, the operation giving rise to no risk of explosions as is the case with potassium. In practice, 66 lb. common soda-ash is well ground up with 28½ lb. slack or small coal and 6½ lb. chalk, and the mixture is put into an iron cylinder 3 ft. 9 in. long, and 5 in. in diameter, coated with fire-clay; this is introduced into a reverberatory furnace, and heated to whiteness; its ends are closed by iron plates, one being traversed by a 1-in. iron gas-pipe, through which the gases and sodium vapour escape,

the latter being condensed by passage through a cooling receiver exactly as in the case of potassium (p. 405, Fig. 159), and falling into a dry iron pot placed beneath, while the escaping carbon monoxide burns with a yellow flame and forms no explosive compound. The operation is made nearly continuous by arranging the cylinders in sets in the furnace, and discharging and recharging them in turn. The actual product is only about $\frac{1}{3}$ of the theoretical yield, owing to losses incurred by part being volatilized and burned, part adhering to the receiver, and part being imperfectly reduced. The metal thus obtained is pure enough for general use, and only needs to be remelted and cast into rods 1 ft. long and 1 in. thick; these will keep in dry air in closed vessels for a long time, becoming covered with a thin coating of oxide which preserves them from further attack; but small pieces should be stored under petroleum.

"W. P. Thompson has proposed a novel method of preparing all the alkali metals which, if successful, would greatly reduce their cost. The reducing agent used is liquid iron, either alone or in conjunction with hydrogen or carbon, the operation being performed in an apparatus resembling a Bessemer converter. In the preparation of sodium, iron mixed with an equal quantity of carbon is treated with caustic soda in the converter, and the sodium said to be formed under these circumstances is simply distilled off." (*Analyst.*) This does not appear to offer much advantage over Gay-Lussac and Thénard's process, already mentioned (the second method spoken of).

Metallic sodium has a silver-white colour and lustre; it is hard at −4° F. (−20° C.), very ductile at 32° F. (0° C.), of a waxy consistence at ordinary temperatures, semi-fluid at 122° F. (50° C.), and melts into a mercury-like liquid at 204° F. (95½° C.); it oxidizes in moist air, volatilizes at a red heat, and has a sp. gr. of 0·9735 at 56° F. (13½° C.); in conductivity of heat and electricity it ranks after gold, and in electro-positiveness after silver, copper, and gold; it forms with potassium an alloy which remains liquid below 32° F. (0° C.), if more than 16 parts potassium are combined with 10 of sodium. It is commercially employed as a reducing agent in the preparation of other metals (aluminium, boron, magnesium); and its amalgam with mercury (see p. 12) is largely used in place of mercury alone for catching fine and dirty gold in the apparatus employed for treating auriferous ores (see Lock's 'Gold').

STRONTIUM.—This member of the alkaline-earth group of metals occurs in small proportions in sea water, and in many brine springs and mineral waters, as well as in most of the calcium minerals; but its chief sources are celestine (its sulphate) and strontianite (its carbonate). Metallic strontium can be prepared by electrolysis of the hydroxide or of the chloride, or by forming a sodio-mercurial amalgam with the chloride. For electrolysis, Bunsen and Matthiessen fill a small porcelain crucible, having a porous cell in the middle, with anhydrous strontium chloride mixed with a little sal-ammoniac, the level of the salt in the cell being much higher than that outside; the negative pole is placed in the porous cell, and consists of a very fine iron wire wound around a stouter one, and covered with a piece of clay tobacco-pipe stem so that only $\frac{1}{16}$ in. appears below, while the positive pole is an iron cylinder put into the crucible around the porous cell; during the operation, the heat is controlled so that a crust forms in the cell, and the metal accumulates under this crust without encountering the oxygen of the atmosphere. In the second process alluded to, the metal is prepared by repeatedly heating a saturated solution of strontium chloride with an amalgam of 2½ oz. sodium and 10 oz. mercury to a temperature of 194° F. (90° C.); the strontium amalgam produced is quickly washed with water, dried between bibulous paper, and heated in a current of hydrogen in an iron crucible, when the mercury volatilizes, and a regulus of strontium is left. The metal has a sp.

gr. of 2·5, and a yellow colour; it is harder than calcium and lead, may be hammered into thin plates, oxidizes quickly in the air, burns when heated, melts at a moderate red heat, and is more electro-negative than the alkali metals and calcium.

TANTALUM.—This curious metal occurs in small quantities in some ores of tin and tungsten, but more abundantly in the uncommon minerals tantalite (containing 49½ to 76¼ per cent. of the oxide), columbite (22¾ to 28½), yttrotantalite (10), and fergusonite (6½). An impure form of the metal (it seems never to have been isolated in a perfectly pure condition) may be prepared from any of these minerals in the following manner. The mineral is finely powdered, and fused with 3 times its weight of acid potassium sulphate; the fused mass is completely boiled out with water; the residue is digested with ammonium sulphide (to remove the tin and tungsten, while the iron is thereby converted into sulphide), washed, and boiled with concentrated hydrochloric acid; tantalum hydroxide is left, and is washed with boiling water, and ignited; the silica generally present in the resulting oxide is got rid of by dissolving in hydrofluoric acid and evaporating with sulphuric, and any trace of niobic acid is removed by adding 1 part potassium fluoride to every 4 parts of the oxide present in the boiling hydrofluoric acid solution, and boiling down till 1 *grm.* of the oxide is contained in 7 *cc.* of the solution; the needle-like crystals of potassium tantalofluoride, which separate out on cooling, are washed till the wash-water gives no orange-red precipitate on standing for 2 hours, but a sulphur-yellow one with tincture of galls, further quantities of this salt being obtained by evaporating the mother-liquor and wash-waters; this salt, mixed with an equal weight of concentrated sulphuric acid, is gradually heated to 752° F. (400° C.); when the residue is boiled out with water, there remains a granular compound of tantalum oxide and sulphuric acid, which is decomposed on ignition, the sulphuric acid being completely removed by adding ammonia carbonate. The metal obtained as a black powder, by igniting potassium fluotantalate with potassium, is soluble only in hydrofluoric acid; it ignites and burns when heated in the air, in chlorine gas, or in sulphur vapour.

TERBIUM.—This metal is found abundantly in samarscite, a mineral containing compounds of niobic acid with terbium, erbium, iron, and yttrium; but it has not yet been completely isolated from its associate erbium.

THALLIUM.—This metal is sparingly distributed in many kinds of iron- and copper-pyrites, and in some lithia-micas, but occurs to the extent of 17¼ per cent. (with about 33¼ per cent. of selenium) in a new Swedish mineral named crookesite. It is most conveniently prepared from the flue-dust deposited in the kiln passages of sulphuric acid works which burn pyrites affording the metal; this is boiled several times in water containing sulphuric acid, the solution is concentrated, and, by adding zinc, the thallium is precipitated in shining plates and needles. A second process, which is said to give a purer metal, is as follows: the flue-dust is boiled with water, and hydrochloric acid is added to the concentrated clear solution; the precipitate is washed, gradually dissolved in half its weight of hot sulphuric acid, and heated till nearly all the sulphuric and all the hydrochloric acid is driven off, when the residue is dissolved in water, the solution is dosed with hydrogen sulphide (to throw down antimony, arsenic, bismuth, mercury, and silver), and to the filtrate is added ammonia, with a view of precipitating any alumina or iron; the concentrated filtrate gives pure thallium sulphate in crystals, whence the metal can be procured by electrolysis or by decomposing with zinc. A third process is described by Bunsen for recovering the metal from crude zinc sulphate containing ½ per cent. of thallium chloride, which consists in leaving metallic zinc in contact with the

solution, when thallium, cadmium, and copper are precipitated in the metallic condition; the deposit is carefully washed with water, and digested with dilute sulphuric acid, when the thallium and cadmium are dissolved; addition of potassium iodide to this solution causes a separation of the thallium iodide, which, on treatment with potassium cyanide, affords the pure metal. This has a sp. gr. of 11·8, a leaden lustre, a bluish colour, and a crystalline structure; it is malleable, so soft as to mark paper, melts at 554° F. (290° C.), and is rapidly dissolved by dilute acids.

THORIUM.—This metal exists as an oxide in some rare minerals, *e. g.* to the extent of 73¾ per cent. in orangeite, 59 per cent. in thorite, and 18 per cent. in monazite, as well as smaller proportions in orthite and gadolinite. It is prepared in the metallic form by heating the chloride with a reducing agent, such as sodium or potassium. The chloride is first obtained by heating the oxide mixed with carbon in a current of chlorine. The metal forms a grey powder, soluble readily in nitric and difficultly in hydrochloric acid, insoluble in aqueous alkalies, taking fire when heated in the air, and having a sp. gr. of about 7·7.

TIN. *Ores.*—Only 2 ores of tin have any commercial importance; these are the peroxide, known as cassiterite or tinstone, and the sulphide, called tin pyrites. The former is by far the more important, and is the chief source from which the metal is derived. It occurs in irregular veins, pockets, and bunches in undisturbed primary rocks, and in minute grains (stream tin) in alluvial deposits resulting from the denudation of rocks containing such veins. The mining of the ore is conducted in the same manner as that generally pursued with the ores of other metals already described, *e. g.* copper.

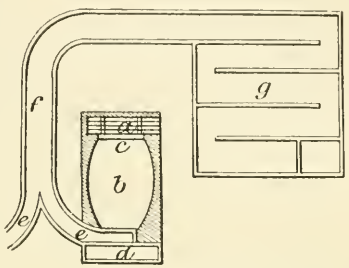
Cleaning and Sorting the ore.—As soon as the ore reaches the surface, it undergoes a rough cleansing process to free it from adhering earthy impurities. This is effected by passing it over a grating under a stream of water. Next it is hand broken to a size convenient for feeding into the stamps, and sorted into heaps according to its character, the main point being to separate the fragments of copper-, iron-, and arsenical pyrites found associated with tinstone, as well as the wolfram. The 3 kinds of pyrites are sold to sulphuric acid manufacturers for the sake of their sulphur, the "cinders" from the copper pyrites being subsequently treated for the recovery of the copper. The ore mixed with wolfram is specially dealt with for the extraction of the tungsten (see p. 455).

Stamping the ore.—The cleaned tinstone is next crushed to powder in a stamp battery, generally of the most antiquated form, driven by a neighbouring stream. The battery consists essentially of a series of heavy pestles, which are raised in succession by a cogged shaft, and fall upon the ore as it is fed in between the pestles and the mortar or sole-plate beneath. As fast as the ore is reduced to powder, it is carried away in suspension by a stream of water flowing through gratings perforated with about 160 holes to the sq. in., and leading to a series of settling pits, where the superior weight of the tinstone causes it for the most part to separate from the other matters, which latter are carried farther away by the water. The separation thus effected is rendered more complete by washing the deposits ("tin witts") on smooth tables termed "racks," where they are brushed about in a gentle stream of water. Various other contrivances are in use, and will be found fully described in André's 'Mining Machinery.'

Calcining the ore.—The object of this operation is the diminution of the sulphur imported by those portions of copper- and arsenical pyrites which it is impossible to completely separate from the tinstone before or after stamping. The calcining may be performed in a reverberatory furnace or in furnaces of special construction. The dimensions and form of the reverberatory furnace are subject to variation, but the general principle is the same in all. The fur-

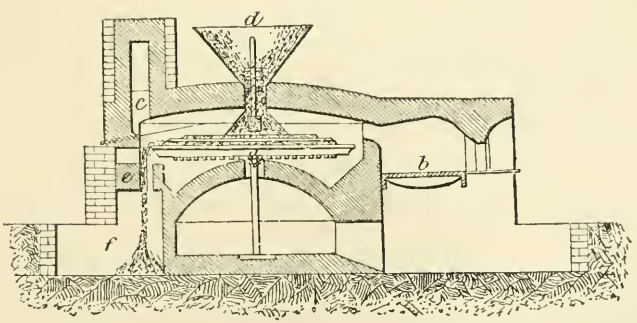
nace is built of stone, with an inside lining of firebrick, and is furnished with a working bottom of the same material. At the rear end is a narrow fireplace, communicating for its entire length with the chamber of the furnace, which may be 9 ft. long, 5 ft. wide in the middle, 4 ft. at the rear, 14 in. high, and 20 in. wide at the working door. The flame from the grate is deflected on to the floor, and escapes through a flue over the working door. The ore is placed in a hopper-like cavity in the crown of the furnace, whence it is discharged as required into the furnace below. Under the floor is an arched pit for the reception of the calcined ore; while the working door is provided with a serrated plate to assist in the employment of a long bar for repeatedly stirring up the charge, which may amount to 10 or 12 cwt. Such a charge requires about a day of 12 hours for its calcination, and consumes 2 cwt. of coal. The roasting converts the arsenic present into oxide (white arsenic), which is largely deposited in long condensing flues built for the purpose. Any copper sulphide in the ore is more or less completely oxidized to sulphate, and this change is further perfected by leaving the roasted mass for some days in a damp state exposed to the air. Fig. 174 shows the arrangement of a reverberatory furnace and its accompanying arsenic condensing chambers: *a*, grate; *b*, calcining hearth; *c*, fire-bridge; *d*, chimney for fire; *e*, flues for vapours issuing from the hearth; *f*, flue leading to the condensing chambers *g*.

Fig. 174.



Another form of furnace often used is that known as Brunton's calciner, illustrated in Fig. 175. It consists of a circular cast-iron table, supported on a central stout iron shaft, suitably stepped in bearings, to allow of its being slowly revolved by the gearing of a toothed wheel fastened on the under side of the revolving bed *a*, which is placed under the dome of a reverberatory furnace, the fireplace *b* being on one side, and the flue *c*, leading to the chimney, on the other. The ore is fed through a hopper *d*, situated in the crown of the arch, and is distributed, and regularly

Fig. 175.



turnel over and thrust from the centre to the circumference. The revolution of the bed of the furnace is effected by the attachment of the machinery to a small water-wheel. The ore having been constantly turned over, and every particle exposed to the oxidizing influence of the heated air passing through the furnace, when it has reached the discharging point *e*, it is there thrust out of the furnace into the "wrinkle" *f*, in a steady small stream, proportionate to a similar stream supplied through the hopper. The rate of supply and discharge is regulated by the rapidity of motion imparted to the revolving bed, which is determined by the amount of time required by the various ores subjected to calcination. It is evident that much less labour is necessary for the working of this, than of the ordinary reverberatory furnace; and a less consumption of fuel is also sufficient for the production of the same effect.

The flue from the calciners is commonly conducted a considerable distance up the side of a hill, to a short chimney-stack, or, better still, a large square tower filled with brushwood or furze. For the first 100 or 150 ft. from the furnace, the flue is built much larger than farther off, with divisional walls to increase the length of circulation of the volatile products from the furnace; doorways are built in the sides of these chambers, and these are closed up with temporary brickwork, or with large stones. At convenient intervals of 1 to 3 months, the flues are opened, and the crude arsenic is removed, packed in casks, and sold to the arsenic manufacturer for refining. The sulphurous acid evolved with the arsenic passes on, and is discharged from the chimney into the surrounding atmosphere, not unfrequently, during damp weather, causing much damage to adjacent vegetation. This might be entirely avoided by the filling of the tower with coke, kept moist with a small stream of water, which would absorb and condense the sulphurous acid.

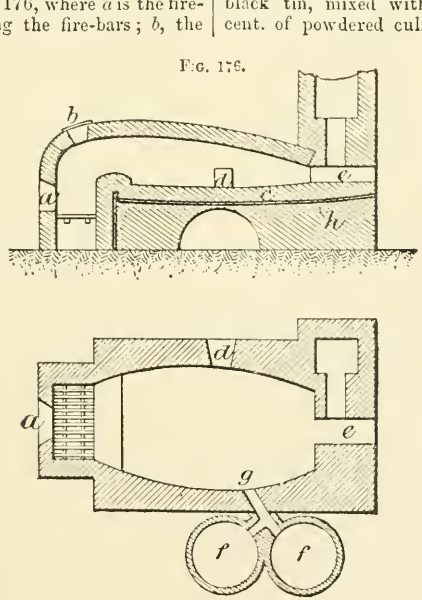
The process of calcination is, with but few exceptions, employed exclusively on dressed ores; but great advantage in many instances would accrue from selecting those ores which contain sufficient iron-, copper-, or arsenical pyrites, to burn of themselves without fuel. The calcination in this case would be conducted in a furnace resembling a small lime-kiln, the ore being supplied at top, and, when burnt out, drawn at the bottom into the ash-pit below the fire-bars, in which water is kept, so that, by the hot burnt ore dropping into it, and being suddenly chilled, it falls to pieces. Ore thus burned is much more easily reduced to powder. From the side of the top of the furnace, the volatile product may be led off to the main flue, with which the reverberatory communicates. The partially calcined ore having been dressed in the usual manner for "witts," the final calcination may be effected in the reverberatory furnace, as already described.

Washing roasted ores.—From the "wrinkle" of the calcining furnace, the burnt ore is removed to the burning-house floors, where it is subjected to a series of washing processes, much more carefully conducted than those in the preparation of "witts." The witts having been burned in separate parcels, according to their size, as "jigged," "fluran," smalls or "smales," "slime," and rough or "rows," they are operated on accordingly; the jigged being simply jigged over again in a copper sieve; the fluran passed through the buddle and tie; and the smaller sizes through a very much more complicated process, consisting first in washing carefully in the buddle, whence it is sized out according to the part of the buddle in which it settles; then of tossing or "tozing," and packing in a kieve, again washing on a hair-sieve in another kieve, or "dilleughing," so as to throw off the light waste into the water, leaving the "crop" tin on the sieve, whence it is thrown into hand-barrows, and conveyed to "hutches," where it is stored. If the witts have been "corrupted" with a "bad brood or mixture," such as iron-pyrites, copper-pyrites, arsenic,

molybdenum, wolfram, &c., the various operations lead to the production of a great number of temporarily refuse matters, which are treated over again according to the best process indicated by examination of samples of the respective heaps. The effect of the washing is first to remove the copper sulphate in solution, whence the metallic copper is recovered by prolonged contact with metallic iron; and secondly to separate the iron oxide in suspension, leaving a mass of "black" tin, containing about 60 per cent. of the metal. This is next smelted.

Smelting.—In this country, smelting is effected in a reverberatory furnace, as shown in Fig. 176, where *a* is the fire-door for cleaning the fire-bars; *b*, the chimney, for the purpose of preventing the oxidizing effect of the stream of air, which would obtain access to the charge, if, as is usually the case with reverberatory furnaces, the working-door were in the side; *f*, iron pans, with fire beneath them, into which the charge is run, when melted, through the tap-hole *g*; *h*, air passage under the hearth. The chimney is usually 40 to 50 ft. in height. The ores, as rendered to the smelter, vary in quality from 12 to 15 in 20 for white tin, or 60 to 75 per cent.; but the assays are always spoken of in the proportions of 20. For the ordinary size furnace, the charge consists of 20 to 25 cwt. of black tin, mixed with 12 to 18 per cent. of powdered culm or anthracite,

Fig. 176.

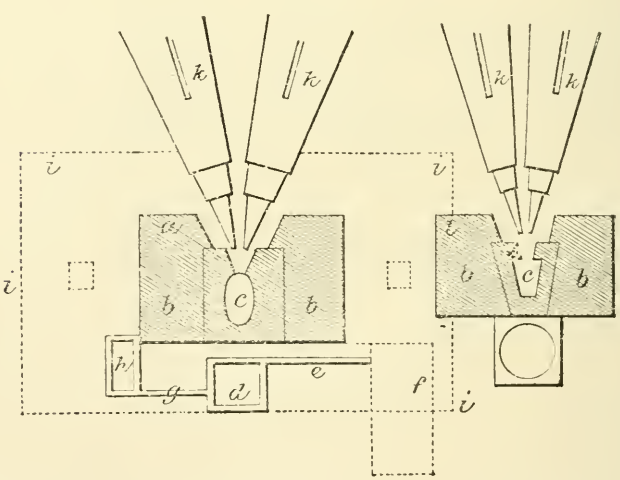


draught-hole, sometimes opened during the skimming of the charge; *c*, a bed of fire-brick, supported on an arch, or on iron bars; *d*, the door for charging; and *e*, the door for working the charge, which is placed at the back under the and a small quantity of slaked lime or fluor-spar, varied according to the proportion of silica contained in the ore. The materials are damped, well mixed, and thrown into the furnace through the door *d*, which is immediately closed,

and the fire is maintained as gently as possible for 6 to 8 hours, or until the whole mass is fused. The charge is then well mixed up, to ensure the complete fusion of any ore remaining unreduced. The doors are again closed for a short time, to recover the heat of the furnace, and to complete the fusion of the charge. They are again opened, and the charge is worked off, through the door *g*, first raking off the top scoria, which is previously chilled by throwing a little damp small coal over the charge. The cautious heating in the early part of the smelting is necessary to prevent the tin oxide from combining with the silica and lime to form a slag which would cause a great loss of tin. When the heat has reached its maximum and the fusion is complete, clay stopper in *g*, when the metal and slag flow into the cast-iron pans *f*. After remaining here for some time, to allow the slag to come to the surface, the slag is skimmed off, and the metal is ladled into cast-iron moulds with a capacity of about 3 cwt. The bulk of the slag remains behind in the furnace and is removed through the door *e*; it is afterwards stamped and washed for the recovery of the tin mingled with it.

Smelting stream tin.—At Altenberg, Germany, it is customary to smelt stream tin in a blast furnace, though this plan entails a greater consumption of fuel and an increased loss of tin. The arrangement of the works is shown in Fig. 177. The large furnace *a* for the fusion of the raw ore is about 14 ft. high, and constructed in the body *b* of

FIG. 177.

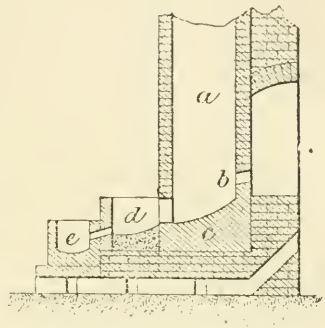


the mass is well stirred up, and some additional culm is introduced. The doors are closed and the fire is urged for about a further 45 minutes, when another stirring is followed by ¼ hour's rest, which permits the heat to increase to the degree necessary for tapping. This is done by knocking out the fire-coarse-grained porphyritic syenite. The crucible of the furnace *c* is built of very refractory fire-brick, of oval form, and having the lower portion lined with a very stiff brasque of charcoal and fire-clay tightly rammed down. From the bottom of the furnace a channel conducts the fused charge into the iron

basin *d*, whence the slag is let off at the side down the inclined plane *e* into the water tank *f*, the metal beneath being run out by the channel *g* into the tank *h* measuring about 18 in. square and 2 ft. deep. The large furnace stands under a dome indicated by the dotted line *i*, 20 ft. long, 12 ft. wide, and 16 ft. high above the top of the furnace, and so constructed as to catch and prevent the waste of the finely powdered ore driven off by the blast. This last is produced by the bellows *l*, driven by a cogwheel on a shaft turned by water power. The furnace is charged through a door on the left about 3 ft. above the hearth. The smaller furnace *l*, about 5 ft. high, and constructed in the same manner as the other, is used only for fusing the slag from the larger furnace. Both furnaces are slowly dried before use. The large one is first charged with fuel and slag; a moderate blast is commenced with, to reduce the most fusible part of the slag before the rest fuses; then the heat is increased till the furnace is fit for working the ore, which is then introduced. After about 4 hours the metal begins to show. The slag is skimmed off the surface of the basin in the bottom of the furnace as fast as it forms, until (in 20 to 24 hours) the basin is full of metal, when it is run out into the front basin. Fresh charges of raw ore are added as required.

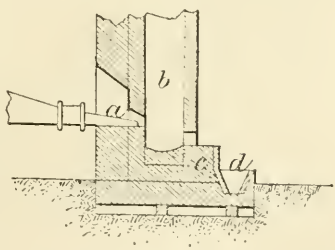
The shape of the blast furnace varies somewhat, as may be seen from the accompanying illustrations. In Fig. 178, the furnace *a* is cylindrical, 10 ft. high, and with a series of compartments above for catching the fine matters forced up by the blast entering at *b*; the sides and sole *c* are of granite, as is also the fore-hearth *d*, which is coated inside with clay and charcoal, for the reception of the metal and slag escaping from the shaft. The stream tin and wood charcoal are repeatedly replenished from the top so as to keep the shaft *a* full; the combustion of the charcoal abstracts the oxygen from the tin oxide, allowing the metallic tin to flow away at the bottom. A flux of some kind is generally charged in with the ore and fuel; this may be quartz (silica) if the ore contains much

Fig. 178.



iron oxide, or lime or "finery cinder" if there is already sufficient silica in the ore. The flux helps to form a slag, which escapes with the liquid metal into the fore-hearth *d*, whence the slag is transferred to a tank of water, leaving the metal to gradually fill the fore-hearth, when it is run through a tap-hole into the pan *e* ready for refining. The furnace employed at Altenberg is shown in Fig. 179: *a* is the blast pipe (twyer); *b*, the furnace; *c*, the inclined plane for the slag; *d*, the fore-hearth.

Fig. 179.



Although the metal produced from the blast furnace is usually better than that obtained from the reverberatory furnace, yet the expense of fuel and the loss of ore are so much greater than with the latter, that the use of the

blast furnace is nearly abandoned. With the reverberatory furnace, for 1 ton of tin produced, the consumption of fuel amounts to $1\frac{3}{4}$ tons, with a loss of 5 per cent. of metal. With the blast furnace, the fuel consumed amounts to about 3 tons of coals, with a loss of metal equal to 15 per cent.

Refining.—The crude metal obtained by the smelting, whether in the reverberatory or in the blast furnace, has to undergo a refining process. The two chief impurities are iron and lead, the former of which may vary between $1\frac{1}{4}$ and $16\frac{1}{2}$ per cent., while the latter ranges from $\frac{1}{4}$ to 10 per cent. The refining may be divided into 2 stages, liquation and tossing.

For the liquation, the reverberatory furnace used in the reducing operation may be employed. It is charged with pigs of the crude metal piled up in such a way as to allow the heat to pass freely through; the fire is urged moderately, and the tin is thus "sweated" out, and flows into one of the pans *f* (Fig. 176) already heated for its reception. The mass of ore in the furnace gradually crumbles down; as room occurs, more blocks of crude metal are charged in, until 5 or 6 tons of fine metal have collected in the pan. The residual mass is either removed from the furnace in its crumbled state, or is fused and run into the other pan *f* for subsequent treatment.

The liquated metal having been accumulated in sufficient quantity in the iron pan, the process of refining is commenced by forcing under the surface of the metal, a bundle of billets of green wood. The steam and gases evolved from the wood cause a violent ebullition, and the production of a frothy scum containing tin oxide, which is skimmed off, and set aside for further treatment, with the slag produced in the first operations. Instead of boiling with green wood, the same effect is sometimes produced by "tossing," or raising the metal in ladles, and pouring, from some height through the air, back again into the pan. When sufficiently boiled or tossed, and skimmed, which process occupies about 3 hours, the metal is allowed to stand undisturbed for another hour, during which time it settles into 3 parts or zones, of which the top is the purest, the middle the next in quality, and the lowest the most impure. The heat of the metal is maintained while in the pan by a fire underneath. When it has stood quiet sufficiently long, the metal is carefully skimmed, and then ladled out into iron moulds, which contain about 3 cwt. The 3 sorts are kept separate, their quality being ascertained by taking a small ladleful, stirring and skimming until sufficiently cold, and then pouring it into a stone ingot-mould, watching the appearance of the metal as it cools. If sufficiently pure to class as "grain" tin, it will remain bright and clear, full, and well rounded on the sides, until quite cold; if only sufficiently good to class as "common" tin, it will remain bright, but not so full and well rounded on the sides, until, at the instant of becoming solid, from the middle of the ingot a frosted crystalline appearance shoots out to the sides. In the third quality, the colour becomes slightly yellowish, and the appearance of the frosted crystalline markings takes place sooner, completely covering the whole of the surface. Examining the ingots when quite cold, by bending them, the remarkable crackling sound characteristic of tin is much greater in proportion as it is purer. The third quality is so impure as to be unfit for commercial purposes, and has to be again refined. The metal is sent to market in the form of ingots of 3 cwt., 1 cwt., or $\frac{1}{2}$ cwt.; or in strips cast in white marble moulds about 2 ft. long, 1 in. wide, and $\frac{1}{2}$ in. thick; or it is rendered in the form known as "grain" tin, which is made by heating an ingot to the highest possible temperature short of melting, and letting it fall, or striking it heavily, when it flies into a mass of crystalline, fibrous fragments. It is said that too low a temperature in melting tin, before casting, prejudicially affects its malleability.

Argentine.—This product—used for printing on cloths and paper—is a tin

moss or sponge, and is obtained by the precipitation of a solution of tin by zinc. The solution, strongly acidulated at first, must be diluted until it contains 3 pints of water to 1 dr. of the tin salt. The sponge having been collected without compression in a sieve, washed with water, and dried by heat, may be brayed with water in a mortar, passed through a hair sieve, and mixed with starch paste for printing. The solution of zinc chloride may be used for soldering, &c., and the grey tin powder for tinning all metals but lead. (*Chron. Industr.*)

Utilization of Scrap Tin.—The vast heaps of scrap tin found about tinware works, and the quantities of refuse tin cans that form such an item in city waste, have often been made the subject of experiment to separate the tin coating from the sheet iron. Melting the scrap gives only a spongy iron, and the extraction of the tin by the action of acids or chlorine gas is too expensive, so that hundreds of tons of this material are wasted every year. Reid's experiments, however, seem to promise a cheap method of recovering both the tin and iron in a pure and useful shape. The tin scraps are placed in a furnace where the temperature and the supply of air can be carefully adjusted. This gives a roasting in free air that causes the film of tin on the iron to oxidize. The alloy of tin and iron under the film of tin is next oxidized, and then the scrap is taken from the furnace, and the coating of oxides on the iron is shaken off by simple machinery. This leaves the iron in a comparatively pure state, while the powdered oxides may be smelted with other tin ores, or, preferably, they may be submitted to the action of hot sulphuric acid, which dissolves the iron oxide, leaving the tin untouched. The tin may then be separated from the solution of iron sulphate, and melted, while the solution may be evaporated to dryness and then placed in retorts to recover the sulphuric acid, the residue in the retorts being valuable in making paints. The waste heat from the retorts is used to assist in roasting the scrap, and in evaporating the solution of iron sulphate. Waste fruit-tins are first roasted to remove the solder that may cling to them, and are then treated by the same process.

Properties and Uses. — Refined tin possesses colour and lustre resembling those of silver, but it is slowly tarnished by exposure to the air. Its hardness exceeds that of lead, and its malleability is such that it may be laminated into foil or leaves of exceeding thinness, but it cannot be drawn into wire. Under friction it exhales a peculiar odour, and communicates an unpleasant flavour to the tongue. Strips of pure tin are flexible but not elastic, and thick bars emit a creaking sound when bent. The metal melts at about 455° F. (235° C.), boils at a white heat, and bears high temperatures in close vessels without volatilization or loss. Heated to redness in contact with air or oxygen, it rapidly passes into the grey protoxide, and later into the peroxide, a yellowish-white powder called "putty powder," much used for polishing. Its sp. gr. is 7·291. Pure tin is little affected by dilute acids and reagents, but is converted into a white powder by nitric acid of medium strength; its resistance to corrosion renders it valuable for plating the surfaces of other more easily destructible metals. It is much more largely used as an accessory to other metals than alone: its importance in plating has already been mentioned, and amongst the alloys in common use it forms a principal ingredient in bronze, gun-metal, bell-metal, Britannia metal, pewter, and solders (see Alloys).

TITANIUM.—This metal occurs chiefly in the 3 minerals anatase, brookite, and rutile, which consist of its pure dioxide, and contain 61 per cent. of the metal; it is also a frequent constituent of magnetic iron and basaltic rocks. Its preparation is rendered difficult by its affinity for the nitrogen in the atmosphere. According to one method, potassium titanofluoride is first produced by fusing titanium dioxide with double the weight of potassium carbonate in a platinum crucible, and dis-

solving the pulverized mass in sufficient dilute hydrofluoric acid in a platinum dish, when the desired salt crystallizes out, and may be dried between bibulous paper and recrystallized from boiling water. A dry mixture of this potassium titanofluoride with potassium is heated in a covered crucible, when the metal is reduced as a dark-grey amorphous powder, the potassium fluoride being removed by water; but the metal almost always contains some nitride. A purer product is obtained as follows: into a porcelain tube filled with hydrogen are brought 2 boats, one containing potassium titanofluoride and the other sodium; the metal is reduced when the tube is heated so that the sodium vapour comes into contact with the potassium salt, and the cooled mass is washed with warm water. The metal is attacked by dilute nitric, sulphuric, and acetic acids, and rapidly dissolves in warm hydrochloric acid; it burns brightly when heated in the air, ignites energetically when heated in oxygen, burns very violently when heated with red lead, and combines with chlorine at high temperatures.

Lewthwaite's process for making titanic steel castings, rods, bars, and for producing various kinds of brass, bronze, and bell alloys, may be thus described: To produce a fine steel casting capable of being planed, turned, filed and highly polished, having a silvery finish, take any common pig or cast iron as it has been run from the furnace or cupola, and whilst at or about its hottest state, after skimming off dirt, sprinkle and well stir into the molten mass about 8 per cent. of titanic steel sand, which has the effect of cleaning or refining the iron to such an extent that a large quantity of scum, slag, or dirt has to be cleared away from the metal before pouring it into the moulds, the product being a strong, fine, and valuable steel casting that may be first tooled and then hardened or tempered as required. For a more silvery steel, introduce into the cast metal at its hottest, say 3 to 8 per cent. of tin before mixing in the sand; or treat the metal with copper in a like manner. In any case, the metal thus produced is much better adapted than any hitherto made for fine strong castings, ship engines, or capstan bearings, and it does not rust like the ordinary metals. To produce rods, bars, or sheets, mix in the titanic sand, by hand or otherwise, as the molten metal runs from the reducing furnace, or afterwards in quantity to produce the desired effect, say 6 to 15 per cent. of the sand. The metal or pig so produced may be treated in the ordinary way of puddling, &c., to produce a very superior class of steel for marine and other uses. Other metals and alloys are similarly treated for crucible castings, &c., producing finer, stronger, choicer, and better articles. Much superior castings, &c., can be produced by this process, and without any appreciable increase of cost. It keeps its polish much better than any other steel, and exceeds in strength by at least 18 to 20 per cent.

TUNGSTEN. — This somewhat uncommon metal occurs in considerable proportions in several minerals, the most important being wolfram (which contains 76½ per cent. of tungsten trioxide), scheelite (80½ per cent.), and scheelitine or stolzite (51 per cent.). There are several methods by which tungsten may be prepared in a metallic form as an incoherent powder, viz:—(1) Calcining an intimate mixture of tungsten trioxide and carbon in a closed crucible. (2) Reducing tungsten trioxide in a current of hydrogen. (3) Reducing tungsten chloride in sodium vapour. (4) Mixing finely-powdered wolfram with 3 per cent. potassium carbonate and 20 to 30 per cent. common salt, heating the mixture to redness for ½ hour, boiling the cooled and pulverized mass with hydrochloric acid, and reducing the resultant pure trioxide in a stream of hydrogen. (5) Adding 1 part commercial sodium tungstate to 2 parts common hydrochloric acid (sp. gr. 1·18 to 1·19), passing steam in till the liquid boils, then adding nitric acid (sp. gr. 1·35) in quantity equal to 4 or 5 per cent. of the sodium salt, and continuing the boiling till the separated tungstic

oxide assumes a dark-yellow colour; this is thoroughly washed, dried, mixed with 10 per cent. finely powdered charcoal and 2 or 3 per cent. rosin dust, heated to whiteness for several hours in a well-closed crucible, pulverized, and freed from charcoal by levigation; the product yields 80 to 90 per cent. metallic tungsten.

Commercially, tungsten is mainly obtained in the form of sodium tungstate, as a bye-product in the metallurgy of tin, by what is known as Oxland's process; this is as follows. The sp. gr. of wolfram is so nearly the same as that of black tin that these cannot be separated by any washing operation; therefore the object aimed at is to convert the wolfram (iron and manganese tungstates) into sodium tungstate, this latter salt being soluble in water, and leaving the iron and manganese as oxides in a very finely divided state. The converting process is carried on in a reverberatory furnace provided with a cast-iron bed; the charge is introduced through a hopper in the crown of the arch, and is spread over the bed so as to be exposed to the flame traversing the furnace; the products of combustion pass over the fire-bridge and down into a flue (formed by a diagonal brickwork partition), which leads them to the front of the furnace, under the iron bed, returning along the other side to the chimney, thus enveloping the whole bed with heated vapours. About ½ ton forms a charge (more or less, according as the mineral is in a granular or a pulpy condition), which consists of an admixture of soda ash with dry ore in such proportions that the soda added is rather more than is required to combine with all the tungstic acid present; the mass is stirred and raked about to ensure all portions being brought to a bright-red heat, and is known to be working well when it frizzles, assumes a moist appearance, and adheres slightly to the tools. A roasting of 2½ to 3 hours' duration should suffice if properly effected, and the product is then better than when a longer period or a stronger heat is necessitated; as soon as ready the charge is withdrawn in successive quantities through a hole in the hearth, and falls into a vault, whence it is transferred as required to the lixiviating pans, and then treated, while still hot, with water; a clear solution of sodium tungstate filters off through the mass of tin ore, and runs into reservoirs, being subsequently either allowed to crystallize, or evaporated to dryness in iron pans, and affording a crude product containing about 70 per cent. of the dry tungstate. For economy sake in some cases, the soda ash used may be replaced by "salt cake" (crude sodium sulphate); but it entails a need of more skilful management.

Metallic tungsten is rapidly attacked by aqua-regia, slowly by nitric acid, and powerfully by boiling potash solution; it is unacted upon by water and by moist or dry oxygen at ordinary temperatures, but burns when heated to redness in air or oxygen, and oxidizes when subjected red hot to the action of steam; it combines with chlorine when heated in it to 482° to 572° F. (250° to 300° C.), and less readily with bromine and iodine. *Alloys*, See pp. 32–33.

URANIUM.—This uncommon metal occurs as carbonate, phosphate, and tantalate in some rare minerals, but its only commercial source is pitch-blende, which contains 40 to 90 per cent. of uranoso-uranic oxide. Several processes are in vogue for extracting uranium from pitch-blende, as follows. (1) The powdered ore is digested with sulphuric acid supplemented by occasional small additions of nitric acid; when the precipitate is converted into a white powder (and partially dissolved), the sulphuric acid in excess is driven off, and the residue is digested in water, affording a deposit of bismuth arsenate and sulphate, lead sulphate, and silica; on passing a current of sulphuretted hydrogen through the warmed filtered solution, the remaining bismuth and lead, with antimony, arsenic, and copper, are precipitated, and the filtrate is then oxidized by nitric acid, and treated with ammonia in

excess; hydroxides of uranium and iron go down in the precipitate, which is washed with ammonia and digested at the boiling point in concentrated ammonium carbonate containing an excess of ammonia, when the yellow ammonio-uranium carbonate crystallizes out on cooling. The small quantity of this metal remaining in the mother-liquor is recovered by precipitating the associated cobalt, nickel, and zinc by adding ammonium sulphide in drops at a time as long as any reaction takes place, and then boiling the filtered solution, when ammonium uranate is deposited. (2) Finely comminuted ore is dissolved in nitric acid, the solution is evaporated to dryness, and the residue is filtered off and washed with water; the filtrate is concentrated to crystallization, the crystals are dried, the mother-liquor is evaporated, and the whole is re-crystallized; the resulting crystals are washed with a little cold water (saving the wash-waters for dissolving a new lot of crude nitrate), dried, and shaken up with ether; the dissolved uranium nitrate crystallizes in needles on the ether evaporating. (3) The practical treatment of the ore at Joachimsthal is said to comprise the following operations: roasting with sodium nitrate and carbonate, lixiviation of the roasted mass, treatment of the residues with sulphuric acid, precipitation of the foreign metals by sodium carbonate, purification of the liquid, and precipitation of the uranium; this precipitation is effected differently, according as it is desired to obtain the product as a light-yellow or an orange-coloured mass. For the former, the liquid is treated with caustic soda until a portion of it on acidulation no longer gives the red reaction with potassium ferrocyanide. To obtain the orange-coloured variety, the sodium carbonate solution is very gradually neutralized with sulphuric acid, avoiding excess.

Metallic uranium may be prepared by covering with potassium chloride in a crucible a mixture of $1\frac{1}{2}$ parts uranous chloride, 3 of dry potassium chloride, and 1 of sodium fragments; the crucible is packed round with charcoal powder in a larger one, and the whole is gradually heated to redness in an air furnace; when the reaction is complete, the heat is increased till it effects fusion of the metal without volatilization of the flux, and the uranium forms a button within a mass of dense black slag. The metal is unaffected by the air, but combines with chlorine and with sulphur; it has a nickel-like colour, and a sp. gr. of 18·33, and is both hard and malleable.

VANADIUM.—This rare metal is a constituent of several uncommon minerals, but its only important sources are twofold,—the mottramite deposits of the Keuper copper beds in Cheshire, and the basic slags produced at the Creusot iron works. A vanadium mineral has been found in the Leadville ores of America; it is coloured orange-red, reddish-yellow, and lemon-yellow. Analysis gave the following results, which make it probable that the mineral is dechenite:—

SiO_2	36·86
PbO	38·51
ZnO	9·07
V_2O_5	9·14
Fe_2O_3	2·59
H_2O	2·41
CO_2	0·48
	99·06

Vanadium salts are prepared from mottramite by the Magnesium Metal Co., before spoken of. They digest the Keuper sandstone, which carries the valuable mineral as a film deposited on the surface of the sand-grains, in strong hydrochloric acid, draw off the acid liquor, and well wash the sand with water; the solution and washings are concentrated, and evaporated down with excess of sal-ammoniac; the ammonia metavanadate which separates out is repeatedly crystallized to get rid of copper and iron, and then gently roasted in a porcelain vessel, whereby fairly pure vanadium pentoxide is obtained; this is rendered purer by passing ammonia gas into water holding the pentoxide in suspension, when solution of ammonium vanadate is formed; this is filtered off,

and evaporated to crystallization in a platinum receptacle.

The process adopted for treating the Creusot slag is as follows. The average composition of the slag is :—

Silica	16·50
Alumina	3·80
Lime	46·30
Magnesia	4·00
Protoxide of iron ..	7·07
Oxide of manganese ..	5·30
Sulphuric acid	0·63
Phosphoric acid ..	13·74
Vanadic acid	1·92
	99·26

Consequently, metallic vanadium is present to the extent of 1·08 per cent. For the Creusot works alone, the quantity of vanadium thus concentrated may be estimated at 13),000 lb. yearly. This is, therefore, an abundant source, from which the authors have succeeded in extracting both the meta-vanadiate of ammonia and certain new vanadic products, more specially applicable to the production of aniline blacks. Their principal procedures are the following :—

(1) Simple Solution of the Crude Slags.—The slags, coarsely broken, are left in excess in contact with hydrochloric acid at the common temperature, until the acid is almost entirely saturated, and the solution marks 64° Tw. It may then be let down to 12° Tw. with water, the silica allowed to settle, and the strength taken. The liquid thus prepared contains vanadium in the hypovanadic state, and, notwithstanding the presence of foreign salts, it may be used as it is in printing. The industrial experiment has been made by one of the authors, who, in the course of more than a year's working, has found no inconvenience from its use.

(2) Preparations with a Base of Hypovanadic Phosphate.—The hydrochloric solution of the crude slags, suitably neutralized and mixed with soda acetate, deposits a copious bluish-grey precipitate, which contains the greatest part of the vanadium in the state of hypovanadic phosphate mixed with other sparingly soluble phosphates. By repeating the same treatment a second time there is obtained a new precipitate, containing 20 per cent. of metallic vanadium, if the original slag contained at least 1·5 per cent. The common slags, which do not reach this standard, may be enriched by a very simple process. To the muriatic solution is added an excess of slag, in powder, which neutralizes the free acid, and precipitates the metals whose phosphates are least soluble, especially vanadium. The first precipitate, which is light and of a greyish white, is taken up in hydrochloric acid, and treated with soda acetate, as above. These preparations, very soluble in acids, have been tried with success in several large print-works.

Meta-Vanadiate of Ammonia.—The phosphate precipitates, obtained by the slag itself, or, better, by an acetate, instead of being enriched and sent out, are dried and roasted at a dull red heat. The powder, at first of a light grey, takes an ochre yellow. It is treated with ammoniacal water, which gives an orange-yellow solution of ortho-vanadiate. It is boiled till colourless, filtered, and the ammonia meta-vanadiate is precipitated in the ordinary manner.—(Witz & Osmond, *Compt. Rend.*)

Metallic vanadium is prepared by reducing the dichloride in perfectly pure hydrogen,—an extremely difficult operation, owing to the necessity for excluding every trace of air and moisture. The metal forms a greyish powder, having a sp. gr. of 5·5 at 59° F. (15° C.); it burns in a flame or when heated in oxygen, and oxidizes slowly in the air; it is insoluble in hydrochloric acid, but slowly dissolves in hot strong sulphuric and in hydrofluoric, and violently oxidizes in nitric acid of all strengths.

YTTRIUM.—This member of the cerium group of metals occurs to the extent of about 34 to 35 per cent. (calculated as oxide) in the rare minerals gadolinite and wöhlerite. It has not been satisfactorily isolated.

ZINC. *Ores.*—Zinc is not one of the most common or widely distributed

metals, and never occurs native. Three of its ores are utilized, viz.:—Red zinc ore, an oxide coloured red by associated iron and manganese oxides, and containing 80 per cent. zinc; blende or black jack, a sulphide yielding 67 per cent. of the metal; and calamine or zinc-spar, a carbonate affording 52 per cent. Of these, blende is by far the most common, forming veins in the sandstones and limestones of lead-yielding districts, and generally accompanied by galena and pyrites; calamine is second in importance, and favours the same geological formations as blende; while red zinc ore is comparatively rare. Of even less individual importance, though frequently associated with calamine, is electric calamine or zinc silicate, giving 64 to 66 per cent. of the oxide. A few analyses of typical examples will be interesting:—

BLENDE.

	Belgium.	Belgium.	England.	Bohemia.
Zinc	66·630	63·000	61·500	61·400
Sulphur	32·630	33·600	33·000	33·150
Iron	0·740	3·400	4·000	2·290
Cadmium	..	..	..	1·500
Gangue	..	..	1·500	..

CALAMINE.

	Wales.	Siberia.	Urals.	Pyrenees.
Zinc carbonate	100·000	95·000	87·300	87·000
Iron carbonate	..	1·500	5·300	3·200
Iron hydrate	..	..	5·300	5·600
Manganese carbonate	..	3·000	..	..
Residue	..	..	0·400	3·600

SILICATE.

	Siberia.	Moresnet.		Siberia.	Moresnet.
Zinc oxide	64·700	66·300	Copper oxide	0·500	..
Silica	25·300	24·900	Tin oxide	..	0·300
Zinc carbonate	..	1·100	Water	9·500	7·400

Extraction of the Metal.—The principle which governs the extraction of zinc from its ores is that the metal is readily volatilized and easily recondensed. The first step necessary with ores other than oxides is a calcination to remove the sulphur or other base and convert the zinc to an oxide; the next step is to smelt the oxide with carbon, by which the carbon and oxygen are combined to form gaseous carbonic acid, while the thus deoxidized metal distils over in vapour and is precipitated again in the solid form.

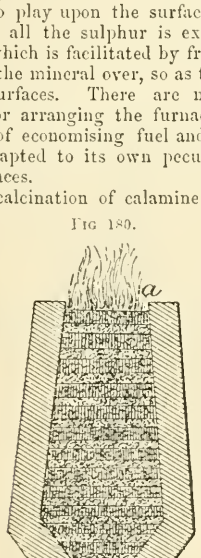
Calcining.—In the case of ordinary calamine, this preliminary calcination may be dispensed with, as the carbonic acid present is as effectually removed in

the subsequent smelting; but with blende and silicious calamine, it is indispensable, in the former instance to drive off the sulphur, and in the latter to get rid of the silica. The ore is previously carefully picked over to free it as far as possible from galena, the lead oxide derived from which in the smelting process would have a corrosive effect upon the crucibles. Next it is crushed and dressed, as other ores, and then submitted to calcination.

The calcination of blende is usually performed in a reverberatory furnace, having either a single hearth, or two hearths one above the other, or a series of three divisions at varying heights in one long hearth. Whatever plan is adopted, the flame from a coal fire is made to play upon the surface of the ore till all the sulphur is expelled, a result which is facilitated by frequently raking the mineral over, so as to expose fresh surfaces. There are numerous plans for arranging the furnaces, with a view of economising fuel and labour, each adapted to its own peculiar circumstances.

The calcination of calamine is more often conducted in a sort of lime-kiln with a small blast, as shown in Fig. 180.

Fig 180.



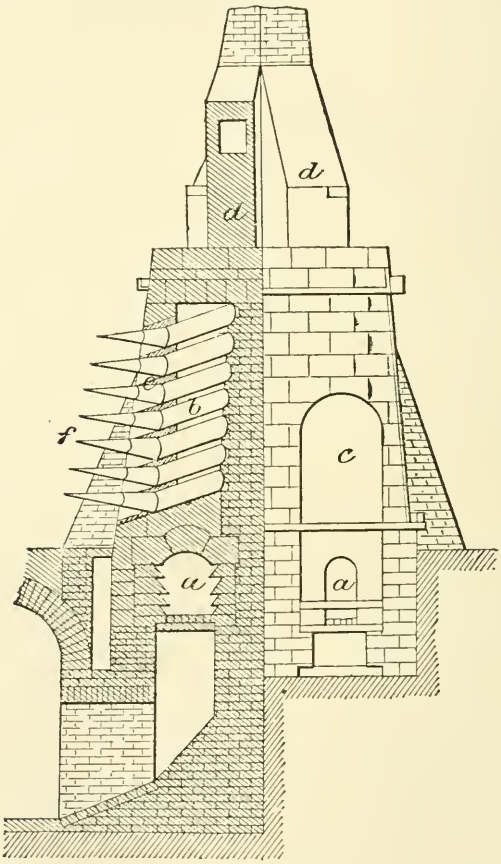
The mixture of powdered ore and fuel (coal or coke) is charged into the furnace at the top *a*, and as the discharging of the calcined mineral takes place at the bottom *b*, the mass gradually descends into increasingly hot parts of the furnace, till it encounters at *c* the full force of the blast issuing from the twyers *d*. The carbonic acid and any sulphur present escape in vapour from the top *a*. The blast is not always availed of. The loss in calcination is about ¼ the weight of the ore charged.

The calcined ore contains the zinc in the form of oxide. It is next reduced to very fine powder, passed through a sieve, and mixed with half its weight of coke or anthracite coal-dust, ready for smelting. If it is associated with much iron oxide and lime, it is mixed with an argillaceous ore, in order that the clay in the latter may be acted upon, rather than the material of the crucibles. There are 3 smelting methods in vogue, known as the Belgian, English, and Silesian, though the English system has been pretty generally superseded by the others.

Smelting: (*a*) *Belgian method.*—The furnace employed at Vieulle Montagne is constructed in sets of 4, and of the form indicated by Fig. 181. The principal parts are a fireplace *a*, tiers of fireclay tubes *b*, flues *c*, for heating the tubes and conveying the products of combustion to the chimneys *d*, each provided with a separate damper at the outlet. The mixture of calcined ore and fuel is filled into the tubes *b*, which measure 3 to 4 ft. long and 6 to 8 in. in internal diameter. To their mouth-ends are fitted short sections of conical cast-iron pipe *e*, penetrating the brickwork, and terminating outwardly in tapering wrought-iron tubes *f*, about 2 ft. long and only 1 in. in diameter at the orifice; the opposite ends of the tubes *b* are closed. The number of tubes arranged in a single furnace varies from 40 to 80. The breastwork of the furnace is strengthened with cast-iron plates and wrought-iron tie-bars. When starting anew, the furnace is gradually heated for 4 days till it attains a white heat;

small charges are then introduced into the tubes, and the iron pipes *f* are luted into place with fire-clay. After the charge has been completed and the pipes are fixed, the fire is urged, and soon copious white fumes appear, denoting that the metal has begun to volatilize. That portion of the distillate which condenses and collects in the cast-iron pipes *e* is the purest; the deposit ac-

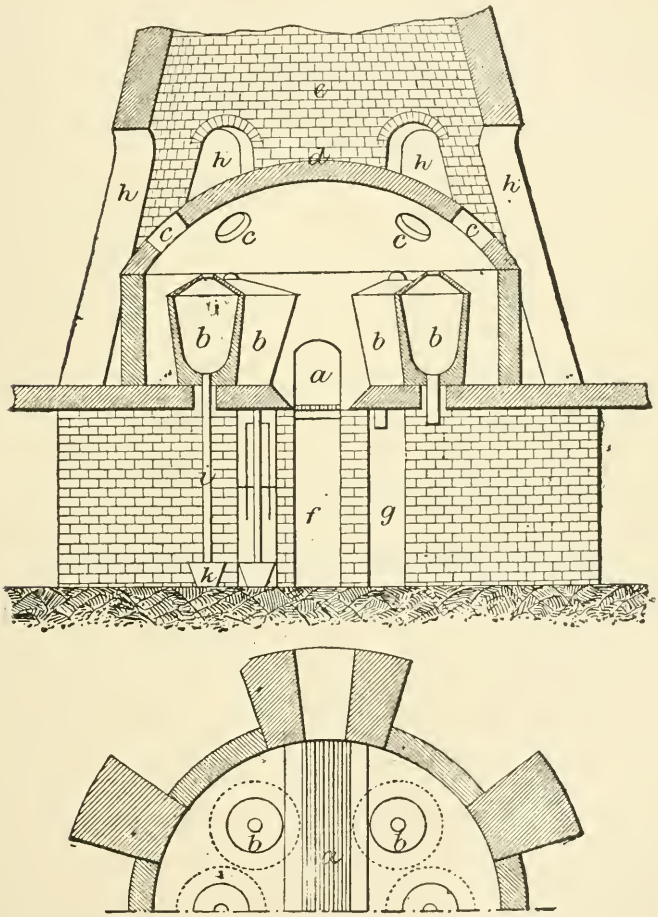
FIG. 181.



quantities of carbonic oxide are evolved from the mouths of the wrought-iron pipes, and burn with a blue flame. As the volume diminishes the colour changes to greenish-white, and then cumulated in the wrought-iron pipes *f* contains much lead in intimate combination with the zinc. This latter product is scraped out as often as necessary, and worked over again in the next charge.

The condensed metal in the cast-iron tubes *e* is raked out in its liquid state about every 2 hours into a large ladle,

Fig. 182.



until the charge is finished, when the tubes *b* are cleaned out and immediately re-charged. A charge generally occupies about 12 hours in smelting, and gives

30 per cent. of the metal it contained; the furnaces endure about 2 months' uninterrupted work, and are then thrown out for repairs. A further proportion of zinc remains in the residue beyond the power of any known process to extract it at a profitable

price; hence ores containing less than 40 per cent. of zinc do not pay to work by this process. The fused zinc obtained is poured into ingot-moulds of generally 70 to 85 lb. each.

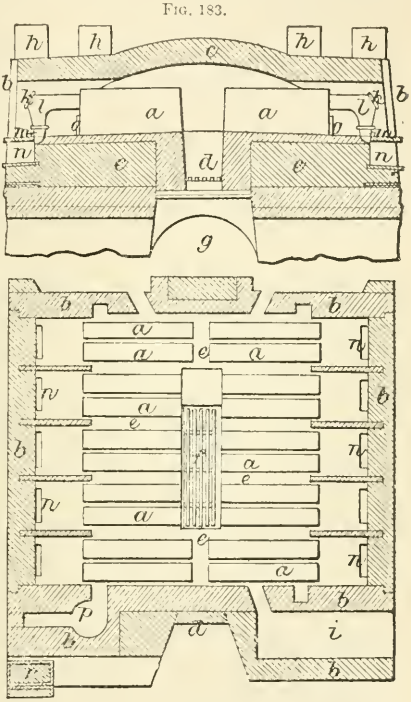
Smelting: (*b*) *English method.*—The construction of the furnace used in the English method of zinc-smelting is illustrated in Fig. 182. The furnace consists essentially of a fireplace *a*, traversing it from front to back, in which burns a coal-fire, where products of combustion envelope the 6 crucibles *b*, and then pass by holes *c* in the dome *d* into the chimney-cone *e*. The passage *f* is the ashpit; a similar passage *g* on each side is for the accommodation of the pipes descending from the crucibles. The large openings *h* in the chimney-cone *e* are provided for the introduction of the crucibles *b* before the completion of the dome *d*, and are left to afford access to the crucibles in working. The crucibles are made of superior fireclay, about 4 ft. deep and 2 ft. 6 in. across, and provided at bottom with iron condense-pipes *i*, 7 in. in diameter and 10 ft. long, the first 2 ft. of which forms a separate piece fixed into the crucible, while the lower 8 ft. can be detached at will. When a new pot has to replace a broken one (they last about 4 months), it is made red hot and conveyed into its place on the hearth through one of the holes *c*; its attached 2 ft. of pipe is thrust through the floor of the hearth, and stopped by a plug of wood or coke. The charge is introduced, and the crucible is left uncovered for a short time, then the lids are carefully luted on. In about 2 hours, a bluish flame commences to appear at the exit of the iron pipe, the vapour penetrating the plug, which, if of wood, is by this time converted into charcoal. The bluish flame is extinguished on attaching the extra length of pipe, which serves as a condenser for the escaping zinc vapours, and conducts the liquid metal into the receptacle *k* containing water. The pipe *i* is apt to become choked with condensed metal, when it may be cleared by taking it off and shaking, or by inserting a red-hot iron rod. Before re-charging a crucible, the residue is cleared out by removing the iron pipe and the plug. The metal collected in the receiver *k* amounts to about 35 per cent.; being contaminated with some oxide formed by contact with the air in its heated state, it is re-melted for the dross to separate (ready for re-smelting), and cast into ingots, under the name of "spelter," but it must not be confounded with the soldering alloy known by the same term.

Smelting: (*c*) *Silesian method.*—The Silesian calamines, yielding less than 20 per cent. of zinc, are smelted in muffle-furnaces, as illustrated in Fig. 183. These furnaces consist of a series of arched ovens *a*, the sides *b* being braced and tied by iron plates and bars, to support the thrust of the central arch *c*. The fireplace *d* and furnace-bed *e* are built of firebricks and lumps. The coal fed on to the grate *f* receives the air necessary for its combustion through the ashpit *g*; the heated vapours surround the 20 muffles *a*, and pass off by flues *h* into the chimney. The muffles *a* are about 3½ ft. long, 1½ ft. high, and 3 in. thick; they are made of a mixture of fireclay and finely-pulverized fragments of old muffles, and are baked to a strong red heat in the auxiliary furnace *i* while the furnace proper is being brought up to the requisite temperature, which requires 8 or 10 days. The previously-calcined calamine, reduced to fragments no larger than a pea, is mixed with an equal volume of fuel (cinders or coke-dust), and charged into the muffles *a* through the orifices *k*, fitted with fireclay stoppers; these orifices *k* are made in the elbows of stoneware pipes *l*, which are attached to the muffles, and are farther prolonged downwards by cast-iron cones and sheet-iron tubes, in which the condensation of the zinc vapour takes place, the metal passing through the outlet *m* and accumulating in the receptacle *n*. The residue left in the muffle is raked out through the door *o* once in 14 hours, having been exhausted of its zinc to within 2 per

cent. The crude metal collected in *n* is re-melted in the clay-lined iron pot *p*, heated by a separate fire, and is cast into ingots *r*. The arch *e* is built of a mixture of fireclay and sand, to a thickness of 9 in., beaten down hard upon a temporary support of wood or brickwork, smoothed over with ashes or sand; the support is removed when the arch has hardened sufficiently to stand alone. Well-made and carefully dried arches last 2 or 3 years; the life of a muffle does not often exceed 4 weeks. In Silesia, gas-furnaces have been tried for zinc-smelting, but it is not very clear whether the advantages gained justify the outlay.

Properties and Uses.—Zinc has a bluish-white colour, and a sp. gr. of 6·8 to 7·2. It is hard enough to bear polishing; brittle but malleable in the cold, showing the greatest ductility and malleability between 212° and 220° F. (100°–104½° C.), and becoming so brittle above these temperatures as to be actually pulverulent. It fuses at allow red heat, and volatilizes at a white heat in closed vessels; in the open air, it ignites at a bright red heat and burns vividly. In a dry atmosphere at ordinary temperatures it is not affected, but rapidly tarnishes and oxidizes in a moist atmosphere. Nearly all acids dissolve it readily, and it is quickly oxidized by caustic potash and soda in water. The commercial metal is never pure, always containing more or less arsenic, cadmium, carbon, copper, iron, and lead; these impurities are eliminated by redistillation. The metal is well adapted for art castings, being much cheaper than bronze, easily coloured externally to resemble that alloy, and taking very clean and sharp impressions from the mould. It is very largely used in the form of thin sheets, which are rolled out between cast-iron cylinders at a temperature not surpassing the limits mentioned above; for this purpose, zinc obtained from calamine is preferable, as being less liable to contain lead. Besides the alloys in which zinc forms an essential ingredient (pp. 13–17, 20–1, 29–30, 34–5, 42), there is an immense consumption for coating iron plates to produce what is known as "galvanized" iron. Zinc is used by engineers chiefly as roof covering, the sheets being made 7 ft. or 8 ft. long and 3 ft. wide. The sheets are stiffened and jointed by lapping over wooden rolls, and are sometimes laid on boarding. The thickness of the sheets is designated by a special gauge, which does not coincide with the B.W.G., and it is best to specify the thickness by the weight per sq. ft. Light sheets of No. 13 gauge, weighing about 16 oz

Fig. 183.



per ft., are sometimes used, but for good work Nos. 14 and 15, weighing 19 oz. to 22 oz. per ft., are generally preferred. The durability of zinc depends mainly on the purity of the spelter from which it is rolled, and the cost is about 3*l.* per ton above the price current for spelter. The wooden rolls used with the sheets cost about 10*s.* per square of roofing surface, and packing for shipment costs about 30*s.* per ton.

Production.—The total production of zinc in Europe attained 203,330 tons in 1880, of which Germany produced 99,405 tons, or nearly half, about two-thirds of which were extracted from Upper Silesia. After Germany comes Belgium with 65,010 tons, then England with 22,000 tons, France 13,715, and Austro-Hungary 3200.

Decorating.—A beautiful and permanent dark or light green coating, resembling enamel, can be applied to all kinds of zinc articles, especially those made of sheet zinc, in the following manner:—5 oz. soda hyposulphite are dissolved in 50 oz. boiling water, and the solution is poured at once, in a fine stream, into $2\frac{1}{2}$ oz. strong sulphuric acid. The milk of sulphur that separates will soon ball together in lumps and settle. The hot liquid containing soda sulphate and sulphuric acid is decanted, and the cleansed zinc is put into it. In a short time it will acquire a very brilliant light-green coating of sulphide, and only needs to be washed and dried. By exposing it repeatedly and for a longer time to this hot bath, the coating grows thicker and the colour darker and more brilliant. The temperature must not fall below 145° F. (63° C.); when it does, the solution should be heated up to 190° F. (88° C.), to obtain a fine and brilliant deposit. By dipping these articles in dilute hydrochloric acid, 1 of acid to 3 of water, sulphuretted hydrogen is evolved, and this enamel-like coating loses its lustre and gets lighter in colour. Aqueous solutions of aniline colours have little effect upon this dull surface, and none on the grey brilliant coating. The effect of marbling can be obtained by moistening the grey zinc and applying hydrochloric acid in spots with a sponge, then rinsing it off, and while still wet flowing over it an acidified solution of copper sulphate, which produces the appearance of black marble. As the zinc has generally a dull surface, it must receive a coat of copal varnish. If $1\frac{1}{2}$ oz. chrome alum and $1\frac{1}{2}$ oz. more soda hyposulphite be added to the solution, the article will have a brownish colour.—C. Puscher, *Ding. Pol. Jl.*

ZIRCONIUM.—This rare metal is found in a few uncommon minerals, chiefly in zircon and hyacinth. It can be prepared as an iron-grey powder by heating together potassium zirconofluoride (obtained by igniting zircon with acid potassium fluoride, or pouring potassium fluoride into an excess of zirconium fluoride) and potassium; or by passing zirconium chloride vapour over ignited sodium; and in the crystalline state by heating potassium zirconofluoride with $1\frac{1}{2}$ times its weight of aluminium in a graphite crucible at a temperature sufficient to fuse iron, and removing excess of aluminium by treating with hydrochloric acid. The metal is oxidized readily by aqua-regia, and is very soluble in hydrofluoric acid, but resists other acids.

APPENDIX.

ALUMINIUM, continued from p. 45.—So much interest is just now being excited in the direction of cheapening the production of this metal, that no excuse is needed for introducing here in the form of an appendix some information on the subject which has appeared in print only since the early portion of this volume was already in type.

In a communication made to the London section of the Society of Chemical Industry in March 1883, Weldon declared that the only manufacturer of aluminium in the world at present is Pechiney, of Salindres, France, and that the process there employed is the same as was worked out by Deville more than a quarter of a century ago. This process consists of 3 successive operations: (1) The preparation of alumina from bauxite, by furnacing the bauxite in admixture with sodium carbonate, dissolving out the resulting sodium aluminate, and then treating the solution so obtained by CO_2; (2) the preparation of double aluminium-sodium chloride, by mixing with carbon the alumina obtained in the first operation, drying the resulting mixture of alumina and carbon, and then heating it in a current of chlorine; and (3) the reduction by free sodium of the Al_2Cl_6 of the double chloride so obtained. These have been already described on pp. 43–4. Weldon directs attention to the relative proportional cost of each operation, which he states as follows:—If the total cost of a unit of aluminium at Salindres be called 100, the cost of the first operation, including that of the bauxite upon which it is performed, is 9·67; that of the second operation is 33·4; and that of the third operation, including the cost of the sodium used in it, and also that of the cryolite employed as a flux, is 56·93. The first operation is thus comparatively inexpensive; the second costs $2\frac{1}{2}$ times as much as the first; and the third costs $1\frac{1}{3}$ times as much as the first and second put together.

It follows that, to produce aluminium at a price appreciably lower than the present cost of aluminium at Salindres, either one must produce it by a process quite different from Deville's, or one must cheapen the second, or the third, or both operations of Deville's process; since to reduce the cost of its first operation even to nothing at all, the second and third operations of it remaining as costly as at present, would cheapen aluminium only by 9·6 per cent.

Weldon then proceeds to show that Webster's invention relates simply to the obtainment of anhydrous alumina from potash alum. If his method of obtaining alumina were 50 per cent. cheaper than the Salindres method, it would thus be capable of reducing the cost of aluminium only by less than 5 per cent. But his method is twice or three times as costly as the Salindres method. Towards the cheapening of aluminium, therefore, Webster has done nothing at all, in Weldon's opinion.

Next, Weldon alludes to the fact that a considerable number of persons, quite independently of each other, are endeavouring to reduce alumina by carbon. It is often rash to say that a proposed thing can never be done; but that alumina can ever be reduced by carbon is surely impossible. When $2\times27\cdot3$ parts of aluminium combine with 3×16 parts of oxygen, there is liberated as

heat a quantity of energy capable of raising 391,600 parts of water from 0° C. to 1° C. To abstract, by purely chemical action, the oxygen of the resulting alumina, leaving its aluminium free, one must cause to react upon the alumina a body by whose combination with oxygen more than 391,600 calories are liberated; and carbon is certainly not such a body. For the reaction

$$2Al_2O_3 + 3C = 2Al + 3CO_2$$

to be possible, the heat of combination of $C + O_2$ must be at least

$$\frac{2 \times 391600}{3} = 261066$$

while for

$$Al_2O_3 + 3C = 2Al + 3CO$$

to be possible, the heat of combination of C + O must be at least

$$\frac{391600}{3} = 130533.$$

But the heat of formation of CO_2 is only 97,000, and that of CO is only 28,800.

The often proposed reaction—

$$Al_2Cl_6 + 6H = 2Al + 6HCl$$

is similarly hopeless, since the heat of combination of Al_2Cl_6 is 321,800; while 6 times that of gaseous HCl is only $6 \times 22,000 = 132,000$.

To arguments of this kind it is often objected that carbon reduces sodium from Na_2O, notwithstanding that the heat of formation of Na_2O is very much greater than the heat of formation of CO. But carbon does not really "reduce" Na_2O. When a mixture of carbon and Na_2O, or, what comes eventually to the same thing, a mixture of carbon and sodium carbonate, is intensely heated, the Na_2O volatilizes, and some of its vapour becomes dissociated into free oxygen and vapour of free sodium; and it is not until dissociation has thus taken place that any of the carbon combines with any of the oxygen of the Na_2O. The carbon acts only by combining, after dissociation has taken place, with some of the oxygen of that part of the Na_2O which has been dissociated by heat, and so preventing re-association on cooling. Unlike Na_2O, however, Al_2O_3 does not undergo dissociation at any temperature attainable industrially.

If, then, we cannot hope to reduce Al_2O_3 by carbon, or Al_2Cl_6 by hydrogen, in what direction can we look for the cheapening of aluminium? It seems to Weldon that there are 4 conceivable resources:

1. The cheapening of Al_2Cl_6,2NaCl.;
2. The substitution for Al_2Cl_6,2NaCl of some other anhydrous compound of Al, not containing oxygen;
3. The substitution for sodium of some cheaper reducing agent; and
4. The cheapening of sodium itself.

Pechiney has already effected important economies in the production of Al_2Cl_6,2NaCl, and will probably effect others. The production of a cheaper haloid salt of aluminium than $Na_2Al_2Cl_6$, would at first blush seem difficult, but is not, Weldon thinks, impossible; and a cheaper agent than sodium, capable of reducing certain salts of aluminium, he believes he could now indicate, if he were free to do so.

As for cheaper sodium, sodium no doubt will be cheapened. To manufacture a ton of sodium at present costs, roughly, between 300*l.* and 350*l.* The quantity of sodium carbonate containing a ton of sodium at present costs in the market about 16*l.* The manufacturer of sodium, however, obtains only about a third of the sodium contained in his raw material. He effects only a partial dissociation of his Na_2O, and to that partial dissociation there succeeds partial re-association. Still, 3 times 16*l.* for raw material leaves 250*l.* to 300*l.* for the cost of extracting 1 ton of sodium from about 7 tons of Na_2CO_3.

The largest item in this excessive cost of extraction is for the vessels in which the Na_2CO_3 is heated in admixture with powdered coal. It has not hitherto been found possible to heat the mixture of Na_2CO_3 and powdered coal to the necessary temperature except in cylindrical wrought-iron vessels of very small diameter, and these small wrought-iron cylinders are so rapidly destroyed that their cost stands for fully $\frac{1}{2}$ of the pre-

sent total cost of sodium, and for nearly $\frac{1}{3}$ of the present total cost of aluminium.

There is surely room here for improvement, and the cost of sodium for this item will doubtless be diminished. Still, one can hardly hope that sodium will ever become cheap enough to permit of aluminium reduced by sodium being largely applied to the many practical uses of which aluminium is capable. A cheaper reducing agent than sodium, and a cheaper artificial ore of aluminium than Al_2Cl_6, $2NaCl$: these, Weldon thinks, are essential to aluminium becoming commonly and extensively employed.

J. Morris, of Uddington, near Glasgow, claims to obtain aluminium by treating an intimate mixture of alumina and charcoal with carbon dioxide. For this purpose a solution of aluminium chloride is mixed with powdered wood-charcoal and lamp-black, then evaporated until it forms a viscous mass, which is shaped into balls. During the evaporation, hydrochloric acid is given off. The residue consists of alumina intimately mixed with charcoal. The balls are dried, then treated with steam in appropriate vessels for the purpose of driving off all the chlorine, care being taken to keep the temperature so high that the steam is not condensed. Now the temperature is raised, so that in the dark the tubes are seen to be at low-red heat, and dry carbon dioxide is passed through. This is said to be reduced by the charcoal to carbon monoxide, which now, as affirmed by Morris, reduces the alumina to aluminium. Although the quantity of the escaping carbon monoxide is in general a good indication of the progress of the reduction, it is nevertheless advisable not to continue the heating of the tubes or vessels until the evolution of this gas has ceased or even nearly ceased, as in consequence of slight differences in the consistence of the balls, some of them give up all their carbon sooner than the others. The treatment of the balls with carbon dioxide for the purpose of the reduction lasts about 30 hours, when the substances are mixed in the proportions of 5 parts carbon to 4 alumina. The metal appears as a porous, spongy mass. It is freed from the residual alumina and particles of charcoal by fusion and mechanical treatment, and then poured into moulds.

Niewerth, of Hanover, suggests a novel process for reducing aluminium. First, ferro-silicon is mixed with aluminium fluoride in proper proportions, and the mixture is submitted to red or melting heat, when the charge is decomposed into volatile silicon fluoride, iron, and aluminium, the 2 latter forming an alloy. To obtain copper-aluminium alloy from this iron alloy, the latter is melted with metallic copper; the copper by reason of its greater affinity, unites with the aluminium, while the iron retains but an insignificant amount of aluminium. On the mass cooling, the copper-bronze and iron separate out in such a manner that both bodies can be readily isolated. In place of the pure aluminium fluoride, cryolite, which occurs in nature, may be advantageously employed, or aluminium chloride may be used. In the latter case, silicon chloride and iron-aluminium alloy are formed. Or, pure silicon and aluminium fluoride, or cryolite, or aluminium chloride may be used, when pure aluminium is obtained.

In the second process, the compound of aluminium with chlorine or fluorine decomposed by any means into a volatile state is brought, strongly heated, into contact with a mixture of 62 parts soda carbonate, 28 of coal, and 10 of chalk, also in a highly heated condition. From this mixture, sodium is disengaged, and this reduces the gaseous aluminium fluoride or chloride in such a manner that the nascent sodium generates free aluminium from the fluoride or chloride as the case may be. In place of the above mixture, others which produce sodium may be employed, or those from which potassium is formed. In another process, Niewerth's newly invented furnace may be employed, but the process may also be carried on in a crucible or other furnace. The furnace in question consists of 3 shaft furnaces made of

fire-resisting material, 2 of which shut by means of some contrivance, *e.g.*, a convex cast-iron cover. These furnaces communicate with the other furnace by channels, which can be closed by slides. Blast pipes are fitted to 2 of the furnaces, and all 3 are fitted with discharge apertures. Short tubes connected with a steam reservoir admit steam to the 2 furnaces, which are filled with some suitable fuel, *e.g.*, coke, and by the admission of the blast are blown very hot. The covers are meanwhile lifted up. The middle furnace is then charged with 3 charges in proper order. The first charge consists of a mixture of soda carbonate (NaO,CO_2) + Carbon (C) + Sulphur (S) + Alumina (Al_2O_3). The second charge is alumina sulphate, the third charge a flux, preferably a mixture of soda and potash chlorides. This furnace must be strongly heated at the beginning of the operation; it is best to fill with coke first, and as soon as that is warm to put the charge on the coke so that it comes to the bottom with the burning coke. A mixing of the charges with coal is usually not necessary.

The process then continues as follows:—The cover of one furnace is shut down, the slide drawn up, and the blast is cut off. A suitable quantity of steam is now admitted, which spreads itself over the glowing coke and penetrates downwards through it, breaking up into its constituent parts oxygen and hydrogen. The oxygen forms with the carbon of the coke carbonic oxide gas, while the hydrogen remains uncombined. The gases thus formed during their passage through the extremely hot coke themselves acquire a very high temperature, and at length pass by a channel into the third furnace where the charge lies. The highly heated gases, carbonic oxide and hydrogen, act upon the charge, so that the first charge breaks up into a combination of sodium sulphide and aluminium sulphide, from which, by means of the second charge (alumina sulphate), free metallic aluminium is formed. Passing into the melting zone, the aluminium will melt, and, if it be drawn off, the flux added thereto will assist the fusion of the aluminium together; it is not, however, absolutely necessary. When the gases generated in the first furnace are too cool, the second furnace is closed by the cover, its coke having been kept hot by the blast, and the processes are repeated.

Instead of the bimetallic sulphide, pure aluminium sulphide may be employed, or a mixture from which it is generated, or, again, pure soda sulphide, potash sulphide, copper sulphide, or other metallic sulphides or analogous compounds producing the same effect alone. In the latter case, aluminium is obtained in combination with the metal of the sulphide. Instead of the one charge alumina + soda carbonate + sulphur + coal, a mixture of alumina, sulphur, and coal only may be introduced; or further, the alumina sulphate may be replaced by alumina. The one charge may also be formed out of sodium sulphide, potassium sulphide, and other metallic sulphides, and the others may be produced from alumina or alumina sulphate.

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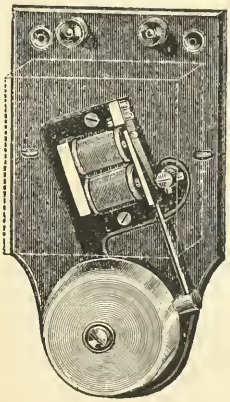

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